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ESTIMATING AND EXPLAINING THE PRODUCTION COST OF HIGH-TECHNOLOGY SYSTEMS: THE CASE OF MILITARY AIRCRAFT

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This study tests relatioships between measures of the state-of-the-art of technology and advances in technology with production cost. The analysis is conducted using a sample of military aircraft. Parametric cost estimating models are developed. Actual production costs are compared with estimated production costs predicted from the models to create measure of cost overruns and cost underruns. A set of factors that are associated with instances of cost over/underruns are identified. These factors reflect aspects of the aircraft program, the political and economic environment at the time of commencement of production on the aircraft program, and the financial condition of the prime contractor.

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ESTIMATING AND EXPLAINING THE PRODUCTION COST OF HIGH-TECHNOLOGY SYSTEMS: THE CASE OF MILITARY AIRCRAFT

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PREFACE

This study was conducted for the Naval Sea Systems Command's Cost Estimating and Analysis Division, Code 017. Funding was provided under the Naval Postgraduate Schools direct funding allotment, Project Code M4L1.

This study represents a continuation of work initiated by Willis R. Greer and reported in "A Method For Estimating and Controlling the Cost of Extending Technology," Naval Postgraduate School Technical Report # NPS-54-88-002, Monterey, CA., March 1988. In that report, Greer:

a) reviewed the literature on the measurement of the state of the art of technology,

b) developed a methodology for measuring the advance in the state-of-the-art represented by a given development program, and

c) established relationships between the advance in technology and development cost.

Greer's research was conducted using a sample of 18 satellite systems.

In a follow-on report, O. Douglas Moses refined the analysis conducted by Greer by using an alternative methodology for measuring advances in the state-of-the-art of technology. That analysis was reported in "Estimating and Controlling the Cost of Extending Technology: A Revision and Extension", Naval Postgraduate

School Technical Report # NPS-54-89-06, Monterey, CA., March 1989.

The objectives of the current study were, as stated in the proposal document:

> Determine whether an association between the degree to which a new system is technologically advanced with respect to it predecessors is an indication of the production costs that can be anticipated. If so, establish a reliable model depicting said association. Determine whether contractors exhibiting high-quality cost control can be distinguished from those who have been less successful in controlling costs. Perform such an analysis. Attempt to discover whether <u>ex ante</u> determinable characteristics are present in contractors which would allow predicting whether good or less-successful cost control can be expected.

This final report is submitted in fulfillment of the agreement. The report is releasable.

Although a continuation of prior research, this report is a self-contained document. Readers who are interested in a general review of studies addressing the measurement of technology are referred to the Greer report cited above. Readers who are interested in a summary of this current report are referred to Chapter VI.

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I. INTRODUCTION

When various components of the Department of Defense (DoD) enter into contractual agreements to procure newly-designed high-technology systems, particularly systems which extend the state-of-the-art of technology, there is considerable uncertainty concerning cost. In order to control the cost of acquisitions, it is important that DoD possess the ability to estimate the cost of producing such systems.

Prior research has shown that useful measures of the state-of-the-art of technology embodied in various systems, and measures of the advance in technology from predecessor systems, can be created. Furthermore, these technology related measures have been shown to be useful in explaining the development cost associated with creating new systems. (See Greer, 1988, for a review.) The purpose of this study is to:

a) determine if technology related measures are useful in explaining the production cost of high-technology systems and develop a cost prediction model using the technology measures, and

b) determine if factors can be identified ex ante (prior to production) which are associated with cost overruns or cost savings (measured relative to expected production cost, predicted from the technology based model).

The analysis is conducted using data for a sample of military aircraft produced during the 1950-1980 period. The organization of the remainder of the study is as follows:

Chapter II describes the process used to select the sample of aircraft and the methodology used to create both technology related measures and measures of production cost.

Chapter III provides an analysis for explaining production cost by technology measures. Regression procedures are employed to construct a model. Measures of cost variances (cost overruns or cost savings) are created by comparing actual production costs with predicted production costs.

Chapter IV hypothesizes that cost variances are associated with factors reflecting characteristics of the aircraft procurement program and economic and political conditions existing prior to the time of production. Findings from tests of the hypotheses are presented.

Chapter V hypothesizes that cost variances are associated with financial characteristics of contractors. Relationships between cost variances and a set of financial ratios are described.

Chapter VI provides a summary and conclusions.

II. SAMPLE AND MEASURES

One objective of this study is to determine and model relationships between technology and production cost. This chapter outlines the approach used to create measures of the state-of-the-art of technology and extensions in technology, and measures of production cost, to be used in later analysis. The analysis is conducted using a sample of aircraft as representative of high-technology systems. Since the measures created are related to the sample, this chapter starts with a discussion of the sample.

SAMPLE

The population for this study was originally defined as U.S. Military aircraft. The sample represents a subset of military aircraft for reasons set out below. The source of data was the U.S. Military Aircraft Cost Handbook [DePuy, et. al., 1983], produced under contract to the Department of Defense, which contains a wealth of performance and cost data on military aircraft manufactured from the early 1950's through the early 1980's.

The handbook contains data for 108 distinct individual aircraft, identified by mission (fighter, attack, patrol, bomber etc.), design and series. For example, the B-52C is a bomber (B), design (52), third series (C). Where successive series of a particular design resulted in virtually indistinguishable aircraft, the handbook combines series into a single program (e.g., A-7A, A-7B -->A-7A/B). This reduced the number of distinct aircraft programs to 80. Since the study is concerned with the state of technology represented by high-technology systems, as reflected in performance and capability (to be discussed in a later section), it was necessary to reduce the sample further. The methodology for assigning a performance measure to aircraft relies on a baseline aircraft, the F-4B, which is used in both fighter and attack missions. Aircraft designed for other missions (strategic bombers and patrol) were deleted (n=19). In addition, because the baseline F-4B is a conventional take-off-and-landing (CTOL) aircraft and performance is related to the take-off-and-landing mode, vertical and short take-off-and-landing aircraft were deleted (n=6). Finally when successive series of a particular design had the same performance, it was assumed that no extension in technology had been achieved and the later series was deleted (n=8). Thus the final sample consists of 47 distinct CTOL fighter and attack aircraft manufactured from the early 1950's through the early 1980's. Table 1 contains a list of the aircraft programs, the prime contractor and the first year of production.

MEASURING THE STATE-OF-THE-ART OF TECHNOLOGY

The literature on technology measurement offers various broad approaches to determining the state-of-the-art (SOA) of technology for a given set of related systems.[1] Each approach requires the knowledge of a number(n) of technology variables reflecting

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[1]See, for examples, Alexander and Nelson, 1973; Dodson and Graver, 1969; Dodson, 1985; Greer, 1988; Knight, 1985; Martino, 1985.

TABLE 1

SAMPLE

OBS	PROGRAM	COMPANY	YEAR
1	F-89C	NRUP	50
2	F-2C	MCDN	51
3	F-9F/H	GRUM	51
4	F-84F	REPB	51
5	F-86D	NOAM	51
6	F-86F	NOAM	51
7	F-89D	NRUP	51
8	A-1E/G/H	DOUG	52
9	F-1B/C/M	NOAM	52
10	F-3A/B/C	MCDN	52
11	F-86H	NOAM	52
12	F-100A/C	NOAM	52
13	A-3A/B	DOUG	53
14	A-4A/B	MCDD	53
15	F-6A	DOUG	53
16	F-11A	GRUM	53
17	F-102A	GDYN	53
18	F/AF-1E	NOAM	54
19	F-100D	NOAM	54
20	F-101A/B	MCDD	54
21	A-1J	DOUG	55
22	F-8A/B/C	VGHT	55
23	F-9J	GRUM	55
24	F-104A/B	LOCK	56
25	A-4C	MCDD	57
26	F-105B/D	REPB	57
27	F-106A/B	GDYN	57
28	F-4A/B	MCDD	59
29	A-4E/F	MCDD	61
30	A-6A	GRUM	61
31	F-4C/D	MCDD	62
32	A-7A/B	VGHT	65
33	F-111A	GDYN	65
34	F-4E	MCDD	66
35	F-4J	MCDD	66
36	F-111B	GDYN	66
37	A-7D	VGHT	68
38	A-7E	VGHT	68
39	F-111D	GDYN	68
40	A-4M	MCDD	70
41	A-6E	GRUM	70
42	F-111F	GDYN	70
43	F-14A	GRUM	71
44	F-15A	MCDD	73
45	A-10A	FAIR	75
46	F-16A	GDYN	78
47	F/A-18A	MCDD	79

NOTATION:
DOUG=DOUGLAS
MCDD=MCDONALD DOUGLAS
GRUM=GRUMMAN
VGHT=VOUGHT
FAIR=FAIRCHILD
NOAM=NORTH AMERICAN
MCDN=MCDONALD
GDYN=GENERAL DYNAMICS
REPB=REPUBLIC
NRUP=NORTHRUP
LOCK=LOCKHEED

distinct properties or characteristics. Each approach combines the variables into a single SOA measure which has a scale independent of the scales of the individual technology characteristics (which are typically measured in differing types of units). The judgmental weighing approach [Gordon and Munson, 1981] express SOA as a direct combination of values of the technology characteristics. Gordon and Munson suggest two general forms of SOA equations.

$$SOA = B_1V_1 + B_2V_2 + ... B_mV_n$$

and

$$SOA = V_1[B_2V_2 + B_3V_3 + ... B_nV_n]$$

where

B_i = judgmentally assigned weights

V_i = the value of the ith technology describing variable.

The first version of the model is a simple linear combination of weighted characteristics, the second version is a multiplicative form intended for use when one variable (V_1) must be present in the system.

The measures used to reflect technology in this study were constructed by The Analytic Sciences Corporation [Timperlake, et. al., 1980] and rely on the judgmental weighing approach. They determined two "figures of merit" for each aircraft. The airframe performance (AP) score reflects the performance and capability of the airframe and engine. The aircraft system performance (ASP) score reflects the capability of the airframe, engine and the electronics, navigation and weapons systems, i.e., the complete aircraft. Each score is a judgmentally weighted function of more basic properties.

Airframe performance is measured by

$$AP = B_1 \times P + B_2 \times R + B_3 \times M + B_4 \times V$$

where

B_1 = Judgmental weights

P = Payload

R = Range and basing mode

M = Maneuverability

V = Useful speed

This formulation is an additive multi-attribute utility function [Keeney and Raiffa, 1976]. Because values of P, R, M, and V are expressed in different units, values for P, R, M and V for individual aircraft were divided by the corresponding values for the baseline F-4B aircraft. This results in all characteristics being expressed as ratios, which can be combined into an overall score.

Weights were determined by the consensus judgment of a large panel of expert operational personnel. Weights were assigned such that the baseline F-4B had an AP score of 10.

Aircraft system performance is measured by

$$ASP = S\ (B_1 \times P \times U + B_2 \times R \times N + B_3 \times M + B_4 \times V)$$

where

S = Survivability modifier, reflecting susceptibility to detection, identification and destruction.

U = Payload utility modifier, reflecting target acquisition and target engagement capability.

N = Navigation coefficient, reflecting internal navigation system capability.

B_i,P,R,M,V = as previously defined.

Again, values of individual characteristics were scaled by the value for the baseline F-4B aircraft, and expert judgment was relied on for determining the functional form and weights of the utility function.

Note that the individual properties reflected in the models represents "output" measures of performance or capability along distinct dimensions. This is consistent with the work of Knight [1985] who distinguishes between structural and functional technology measures. Structural measures capture physical characteristics, i.e., "what the system looks like". Functional measures capture capabilities, i.e., "what the system does". Measures of function or output can be used to compare systems of differing structure.

These two measures were taken as summary indicators of the SOA of technology embodied in the aircraft, reflecting their functional capability. Three technology SOA measures to be used in later analysis were defined as follows:

1. Platform (Airframe and Engine) Technology (PLATTECH) = AP.
2. Flyaway Aircraft System Technology (FLYTECH) = ASP
3. Weapons and Avionics System Technology (SYSTECH) = ASP/AP.

The SYSTECH measure is derived from the two others and is a rough attempt to capture the degree to which the technology in weapons systems and avionics systems enhances airframe and engine capability to achieve flyaway aircraft system capability.[2]

When speaking of the three technology measures collectively, the expression "TECH" will be used. Values of the TECH measures for the sample are in Table 2.

MEASURING EXTENSIONS OF TECHNOLOGY

Various researchers have developed methods for measuring extensions in technology (see Dodson, 1985; Greer, 1988, for reviews). One common approach relies on the idea of the "year-of-technology" [Alexander and Nelson, 1972; Greer and Moses, 1989]. In this approach, time is related to technology measures in a multiple regression:

$$Y = a + b_1X_1 + b_2X_2 + \dots + b_nX_n + e$$

where

Y = actual year the system become operational.

b_i = regression coefficients

X_i = technology measures

e = residual

A predicted value from the regression equation for an individual system represents the "year-of-technology" for that system. If the actual year a given system was produced is less than its year-of-technology, it can be said that the system was produced "ahead of its time" and represents an advancement in technology.

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[2]Dividing ASP by AP is consistent with the idea that the components in the AP formula have been multiplied by modifiers to arrive at ASP.

TABLE 2

INITIAL TECHNOLOGY MEASURES

OBS	PROGRAM	PLATTECH	SYSTECH	FLYTECH
1	A-1J	6.57	0.50837	3.34
2	A-1E/G/H	6.57	0.50837	3.34
3	A-3A/B	12.84	0.83645	10.74
4	A-4C	6.22	0.87621	5.45
5	A-4M	7.33	1.16235	8.52
6	A-4A/B	6.84	0.57456	3.93
7	A-4E/F	7.22	1.00693	7.27
8	A-6A	12.13	1.14015	13.83
9	A-6E	12.13	1.84666	22.40
10	A-7D	10.73	1.50699	16.17
11	A-7E	11.59	1.70578	19.77
12	A-7A/B	11.57	1.04581	12.10
13	A-10A	11.03	1.09882	12.12
14	F-1B/C/M	5.90	0.89661	5.29
15	F/AF-1E	6.05	0.89917	5.44
16	F-2C	6.13	0.63785	3.91
17	F-3A/B/C	7.30	1.23562	9.02
18	F-4E	10.17	1.37266	13.96
19	F-4J	10.31	1.29874	13.39
20	F-4A/B	10.31	0.90398	9.32
21	F-4C/D	10.00	1.00700	10.07
22	F-6A	7.60	0.99737	7.58
23	F-8A/B/C	8.40	1.00000	8.40
24	F-9J	4.72	0.85169	4.02
25	F-9F/H	5.00	0.83800	4.19
26	F-11A	6.35	0.91339	5.80
27	F-14A	14.44	2.18213	31.51
28	F-15A	12.11	1.33278	16.14
29	F-16A	11.56	1.35727	15.69
30	F/A-18A	11.60	2.19138	25.42
31	F-84F	7.85	0.65350	5.13
32	F-86D	5.31	0.69303	3.68
33	F-86F	5.09	0.79175	4.03
34	F-86H	6.08	0.93421	5.68
35	F-89C	3.72	0.66129	2.46
36	F-89D	4.72	0.85805	4.05
37	F-100D	6.25	0.95840	5.99
38	F-100A/C	5.51	0.87114	4.80
39	F-101A/B	9.69	1.37771	13.35
40	F-102A	8.02	1.21072	9.71
41	F-104A/B	6.64	1.02259	6.79
42	F-105B/D	11.68	1.27226	14.86
43	F-106A/B	9.58	1.36221	13.05
44	F-111A	15.45	1.19482	18.46
45	F-111B	16.48	1.50546	24.81
46	F-111D	16.48	1.47998	24.39
47	F-111F	16.48	1.88167	31.01

As simplistic as this method seems, related work by Lienhard [1979] tends to support the concept. His paper studied the rate at which technology is improved, and how (whether) this rate changes through time. He studied several forms of technology (clocks, steam power, land transportation, low temperatures, air transportation) over extended time periods. The most relevant observation to come from Lienhard's study was that the rate of improvement of a particular technology, once established, does not change. If this is correct, there could be some major implications for the cost, and even the feasibility, of attempting to effect technological advances "before their time". If a desired advance could normally be expected to occur only by some quasi-naturally established date, attempts to accelerate this process would be very costly. Accordingly, the year-of-technology approach may be well reasoned.

The essence of the year-of-technology approach is to relate technology to time and use deviations from the time line as indicators of the technology advancement represented by individual systems. A similar approach is used here, but TECH is treated as the dependent variable rather than time. (Since summary technology variables are used, rather than many technology characteristics, they can be used as the dependent variable with results that are equivalent but easier to display and discuss.)

Results of separately regressing the three TECH variables against the year in which the aircraft were first operational (YEAR) are shown in Table 3. Not surprisingly, in each case coefficients for YEAR are positive and significant, indicating that technology increases with time. The relatively high R^2 values indicate that time explains a large proportion of the technology variance among the aircraft.

Plots of the three TECH measures over time are displayed in Figures 1, 2, and 3. The A-6E is circled in the figures. Observing Figure 1, we can see that the A-6E falls approximately on the trend line. The technology embodied in the A-6E platform was not in excess of the average state-of-the-art of platform technology at the time of the A-6E's production. Figure 2 shows that the weapons and avionic systems in the A-6E were advanced relative to the average state of systems technology. The result (Figure 3) was a flyaway aircraft also advanced relative to the average trend in aircraft technology at the time of the A-6E's production.

These observations can be generalized to define three variables reflecting technological complexity or extension:

1. STAND: the average state of the art of technology at the time of production of a system. (For any individual aircraft this is the predicted value from the trend line.)

2. ADVANCE: the extension in technology beyond the state of the art. (For any individual aircraft, this is the residual from the regression model, or the deviation from the trend line.)

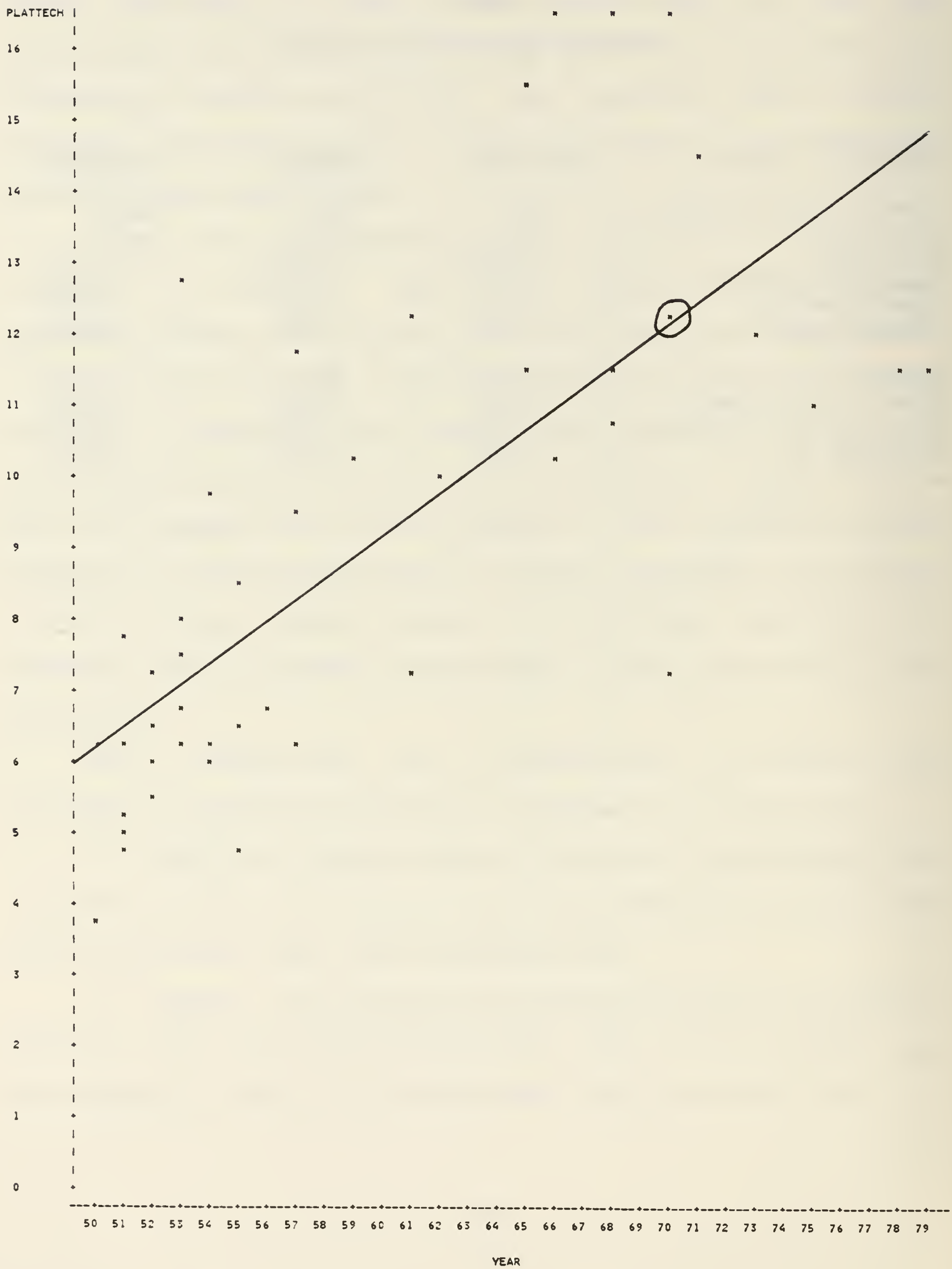
TABLE 3

REGRESSION OF TECH ON YEAR

Dependent Variable	PLATTECH	SYSTECH	FLYTECH
Independent Variable	YEAR	YEAR	YEAR
Intercept	-8.619	-1.038	-30.943
YEAR Coefficient	.2971	.0362	.7063
Coefficient t	7.011	7.902	8.386
Significance	.0001	.0001	.0001
Model F	49.16	62.44	70.32
Model Significance	.0001	.0001	.0001
R^2	.5221	.5812	.6098
Adjusted R^2	.5115	.5719	.6011

FIGURE 1

PLOT OF PLATFORM TECHNOLOGY OVER TIME



NOTE: 3 OBS HIDDEN

FIGURE 2

PLOT OF SYSTEM TECHNOLOGY OVER TIME

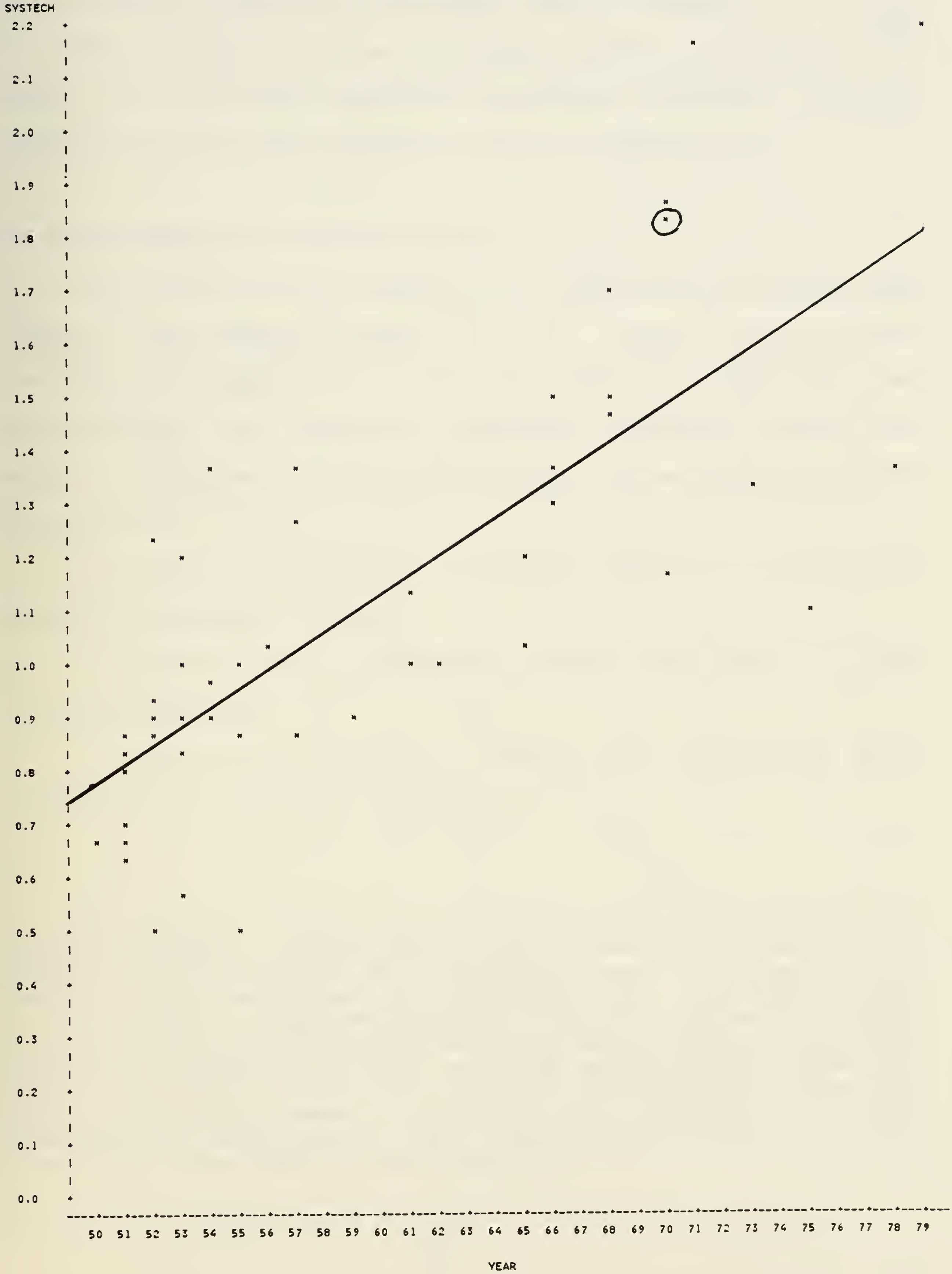


FIGURE 3

PLOT OF FLYAWAY TECHNOLOGY OVER TIME

NOTE: 4 OBS HIDDEN

3. REACH: the total technology embodied in the system. (For any individual system this is simply STAND + ADVANCE.)[3]

Table 4 contains values of STAND, ADVANCE and REACH for the sample for the three kinds of technology, PLATTECH, SYSTECH, FLYTECH, denoted with prefixes P,S and F, respectively.

THE MEASUREMENT OF PRODUCTION COST

All cost data for the aircraft were taken from the US Military Aircraft Cost Handbook (Depuy, et. .al., 1983). This section describes the steps taken to arrive at a production cost figure for each aircraft that could be considered comparable across the sample. Determination of comparable cost figures were hampered by three factors:

A. Costs were incurred at different points in time when the value of the dollar differed.

B. Aircraft were not purchased singly, but rather in "lots" of varying quantity.

C. Cost per unit tends to decline with additional units produced due to production "learning".

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[3]Note, there are alternative ways of determining measures of STAND and ADVANCE. Rather than using a trend line to reflect the average state-of-the-art of technology, one could designate a specific individual system as a reference point. Candidates might be a) an immediate predecessor system or b) the predecessor system with the greatest REACH (maximum predecessor technology). The technology embodied in either reference system would constitute STAND, and ADVANCE would be measured as deviations from the specific reference system. (Of course the reference system would change as time progressed.) These alternatives were explored with no material enhancement of the analysis.

TABLE 4

MEASURES OF STAND, ADVANCE AND REACH

OBS	PROGRAM	PSTAND	PADVANCE	PREACH	SSTAND	SADVANCE	SREACH	FSTAND	FADVANCE	FREACH
1	A-1J	7.7244	-1.1544	6.57	0.95367	-0.44530	0.50837	7.9013	-4.5613	3.34
2	A-1E/G/H	6.8329	-0.2629	6.57	0.84505	-0.33668	0.50837	5.7825	-2.4425	3.34
3	A-3A/B	7.1301	5.7099	12.84	0.88126	-0.04481	0.83645	6.4887	4.2513	10.74
4	A-4C	8.3188	-2.0988	6.22	1.02608	-0.14987	0.87621	9.3138	-3.8638	5.45
5	A-4M	12.1819	-4.8519	7.33	1.49676	-0.33441	1.16235	18.4951	-9.9751	8.52
6	A-4A/8	7.1301	-0.2901	6.84	0.88126	-0.30670	0.57456	6.4887	-2.5587	3.93
7	A-4E/F	9.5074	-2.2874	7.22	1.17090	-0.16398	1.00693	12.1388	-4.8688	7.27
8	A-6A	9.5074	2.6226	12.13	1.17090	-0.03076	1.14015	12.1388	1.6912	13.83
9	A-6E	12.1819	-0.0519	12.13	1.49676	0.34990	1.84666	18.4951	3.9049	22.40
10	A-7D	11.5876	-0.8576	10.73	1.42435	0.08264	1.50699	17.0826	-0.9126	16.17
11	A-7E	11.5876	0.0024	11.59	1.42435	0.28143	1.70578	17.0826	2.6874	19.77
12	A-7A/B	10.6961	0.8739	11.57	1.31573	-0.26992	1.04581	14.9639	-2.8639	12.10
13	A-10A	13.6677	-2.6377	11.03	1.67779	-0.57897	1.09882	22.0264	-9.9064	12.12
14	F-18/C/M	6.8329	-0.9329	5.90	0.84505	0.05156	0.89661	5.7825	-0.4925	5.29
15	F/AF-1E	7.4273	-1.3773	6.05	0.91746	-0.01829	0.89917	7.1950	-1.7550	5.44
16	F-2C	6.5358	-0.4058	6.13	0.80885	-0.17100	0.63785	5.0762	-1.1662	3.91
17	F-3A/B/C	6.8329	0.4671	7.30	0.84505	0.39057	1.23562	5.7825	3.2375	9.02
18	F-4E	10.9932	-0.8232	10.17	1.35193	0.02073	1.37266	15.6701	-1.7101	13.96
19	F-4J	10.9932	-0.6832	10.31	1.35193	-0.05319	1.29874	15.6701	-2.2801	13.39
20	F-4A/B	8.9131	1.3969	10.31	1.09849	-0.19452	0.90398	10.7263	-1.4063	9.32
21	F-4C/D	9.8046	0.1954	10.00	1.20711	-0.20011	1.00700	12.8451	-2.7751	10.07
22	F-6A	7.1301	0.4699	7.60	0.88126	0.11611	0.99737	6.4887	1.0913	7.58
23	F-8A/8/C	7.7244	0.6756	8.40	0.95367	0.04633	1.00000	7.9013	0.4987	8.40
24	F-9J	7.7244	-3.0044	4.72	0.95367	-0.10197	0.85169	7.9013	-3.8813	4.02
25	F-9F/H	6.5358	-1.5358	5.00	0.80885	0.02915	0.83800	5.0762	-0.8862	4.19
26	F-11A	7.1301	-0.7801	6.35	0.88126	0.03213	0.91339	6.4887	-0.6887	5.80
27	F-14A	12.4790	1.9610	14.44	1.53296	0.64917	2.18213	19.2014	12.3086	31.51
28	F-15A	13.0734	-0.9634	12.11	1.60538	-0.27259	1.33278	20.6139	-4.4739	16.14
29	F-16A	14.5592	-2.9992	11.56	1.78641	-0.42914	1.35727	24.1452	-8.4552	15.69
30	F/A-18A	14.8564	-3.2564	11.60	1.82261	0.36877	2.19138	24.8515	0.5685	25.42
31	F-84F	6.5358	1.3142	7.85	0.80885	-0.15534	0.65350	5.0762	0.0538	5.13
32	F-86D	6.5358	-1.2258	5.31	0.80885	-0.11581	0.69303	5.0762	-1.3962	3.68
33	F-86F	6.5358	-1.4458	5.09	0.80885	-0.01710	0.79175	5.0762	-1.0462	4.03
34	F-86H	6.8329	-0.7529	6.08	0.84505	0.08916	0.93421	5.7825	-0.1025	5.68
35	F-89C	6.2386	-2.5186	3.72	0.77264	-0.11135	0.66129	4.3700	-1.9100	2.46
36	F-89D	6.5358	-1.8158	4.72	0.80885	0.04921	0.85805	5.0762	-1.0262	4.05
37	F-100D	7.4273	-1.1773	6.25	0.91746	0.04094	0.95840	7.1950	-1.2050	5.99
38	F-100A/C	6.8329	-1.3229	5.51	0.84505	0.02609	0.87114	5.7825	-0.9825	4.80
39	F-101A/8	7.4273	2.2627	9.69	0.91746	0.46025	1.37771	7.1950	6.1550	13.35
40	F-102A	7.1301	0.8899	8.02	0.88126	0.32947	1.21072	6.4887	3.2213	9.71
41	F-104A/8	8.0216	-1.3816	6.64	0.98987	0.03272	1.02259	8.6075	-1.8175	6.79
42	F-1058/D	8.3188	3.3612	11.68	1.02608	0.24618	1.27226	9.3138	5.5462	14.86
43	F-106A/B	8.3188	1.2612	9.58	1.02608	0.33613	1.36221	9.3138	3.7362	13.05
44	F-111A	10.6961	4.7539	15.45	1.31573	-0.12091	1.19482	14.9639	3.4961	18.46
45	F-111B	10.9932	5.4868	16.48	1.35193	0.15353	1.50546	15.6701	9.1399	24.81
46	F-111D	11.5876	4.8924	16.48	1.42435	0.05563	1.47998	17.0826	7.3074	24.39
47	F-111F	12.1819	4.2981	16.48	1.49676	0.38492	1.88167	18.4951	12.5149	31.01

The raw data available consisted of costs and quantities per lot. The following procedures were employed to transform the available data into comparable cost figures.

1. All lot costs were converted to fiscal year 1981 dollars using Office of Assistant Secretary of Defense, Comptroller, composite price indices for major commodity procurement.

2. Cumulative quantities at the end of each lot were determined by summing the quantities in all preceding lots.

3. Cumulative average costs (FY81) at the end of each lot were determined by summing the costs of all preceding lots and dividing by the cumulative quantities.

4. Learning curves of the following form were fit to the quantity and cumulative average cost series:

$$C_Q = AQ^B$$

where

C_Q = Cumulative average cost for quantity Q

Q = Cumulative quantity

A = Cost of the first unit (estimated by the fitting procedure)

B = Constant, estimated by the fitting procedure.

5. The cumulative average cost of producing 100 units, CAC(100), was determined by setting Q at 100 and re-entering the learning curve to solve for C_Q.

This procedure is ad hoc but does provide a comparable average cost figure at a comparable quantity for all aircraft, taking into consideration the different learning rates experienced on different aircraft programs. The result is an average cost per unit of producing 100 aircraft.[4]

Cost data was available for three separate cost categories for each aircraft:

Airframe cost
Airframe plus engine cost
Total flyaway cost

The approach described above was applied to the three separate cost categories resulting in three variables to be used in the analysis:

FRAMCOST: CAC(100) for airframe cost.
PLATCOST: CAC(100) for aircraft platform (airframe & engine) cost.
FLYCOST: CAC(100) for flyaway aircraft cost.

Note that there is a direct correspondence between PLATCOST and the previously discussed PLATTECH measure, and between FLYCOST and FLYTECH. In these cases, the TECH variables measure technology and the COST variables measure cost for analogously defined components of the aircraft. FRAMCOST is a cost measure for airframes, but there are no corresponding TECH measures. (Without an engine the aircraft can't fly, so no separate measure of airframe performance or technology is possible.) Technology measures for platforms will be used when attempting to explain airframe costs. Additionally, there are TECH measures for systems but no analogous cost measure. Technology measures for systems will be used in

[4]For discussions of learning curves and their relationship to production cost see Kaplan [1982], Liao [1989] and Womer [1979]. For more detail on the specific procedures used to determine CAC see DePuy, et. al. [1983]. The convention of determining CAC at 100 units has been adopted by other researchers. See, for example, Dodson [1977].

some of the tests explaining FLYCOST, since the cost of avionics and weapons systems are included in the total flyaway cost.

Table 5 contains the COST measures for the aircraft in the sample (measured in millions of FY81 dollars). Missing historical data for some of the sample aircraft resulted in missing COST measures. Those aircraft were delete from further analysis. Table 5 also contains a SERIES variable, to be discussed in the next chapter.

TABLE 5

UNIT PRODUCTION COST MEASURES

OBS	PROGRAM	FRAMCOST	PLATCOST	FLYCOST	SERIES
1	A-1J	.	.	.	.
2	A-1E/G/H	1.212	1.557	1.703	0
3	A-3A/B	5.136	6.007	7.815	1
4	A-4C	1.669	1.895	2.100	0
5	A-4M	2.225	2.927	3.714	0
6	A-4A/B	1.603	1.859	1.917	1
7	A-4E/F	1.875	2.436	2.675	0
8	A-6A	11.286	12.421	13.123	1
9	A-6E	7.656	8.883	10.846	0
10	A-7D	2.950	3.847	5.012	0
11	A-7E	3.901	4.855	5.000	0
12	A-7A/8	3.217	4.511	5.272	1
13	A-10A	4.196	5.748	7.272	1
14	F-1B/C/M	2.229	2.297	2.388	1
15	F/AF-1E	.	.	.	.
16	F-2C	.	.	.	.
17	F-3A/B/C	3.419	4.205	4.710	1
18	F-4E	3.649	4.479	5.919	0
19	F-4J	3.511	4.416	5.924	0
20	F-4A/B	7.202	8.802	9.613	1
21	F-4C/D	.	.	5.753	0
22	F-6A	.	.	.	.
23	F-8A/B/C	3.746	4.334	4.475	1
24	F-9J	.	.	.	.
25	F-9F/H	0.655	0.856	0.939	1
26	F-11A	.	.	.	.
27	F-14A	13.082	17.333	23.901	1
28	F-15A	10.252	15.446	19.356	1
29	F-16A	4.045	6.069	9.641	1
30	F/A-18A	18.854	22.197	23.968	1
31	F-84F	6.520	6.020	5.943	0
32	F-86D	0.752	1.118	1.458	0
33	F-86F	0.887	1.028	1.095	0
34	F-86H	.	.	.	.
35	F-89C	.	.	.	.
36	F-89D	2.471	2.831	3.496	0
37	F-100D	1.698	2.426	2.659	0
38	F-100A/C	2.939	3.709	3.856	1
39	F-101A/B	5.771	6.735	7.291	1
40	F-102A	6.802	8.125	9.206	1
41	F-104A/B	2.004	3.830	3.773	1
42	F-1058/D	10.047	10.952	12.280	1
43	F-106A/8	7.014	7.897	12.016	1
44	F-111A	.	.	23.510	1
45	F-1118	.	.	.	.
46	F-111D	.	.	24.141	0
47	F-111F	9.827	14.121	20.897	0

III. PRODUCTION COST AND TECHNOLOGY

HYPOTHESES AND TESTS

The initial analysis concerns the association between production cost and the SOA of technology in the aircraft produced. Can technology measures reliably predict production cost? The first hypothesis is that production cost increases with increases in the SOA of technology (the level of technological complexity). STAND reflects the average SOA of technology at the time of the commencement of production of an aircraft.

H_1: Production Cost = + f (STAND)

The second hypothesis is that production cost increases with the degree of technological extension of a program. ADVANCE captures this notion.[5]

H_2: Production Cost = + f (ADVANCE)

The third hypothesis follows from the mixed nature of the sample. The sample includes some aircraft which are the first series of a new design (eg. F-111A) and some which are follow-on series of an existing design (e.g. F-111B, F-111D, F-111F). It is reasonable to argue that sufficient production learning would occur during the first series of new design so that follow-on series would experience some reduction in cost. Hence

H_3: Production Cost = + f (first series of new design)

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[5]REACH is a linear combination of STAND and ADVANCE and, hence, redundant for testing purposes; it contains no additional information.

A dummy variable (SERIES) was created to capture this idea. SERIES was coded 1 for the first series of a new design and 0 for a follow-on series of an existing design.

Operationally, the hypotheses imply the following multiple regressions:

FRAMCOST = + f (PSTAND, PADVANCE, SERIES)

PLATCOST = + f (PSTAND, PADVANCE, SERIES)

FLYCOST = + f (FSTAND, FADVANCE, SERIES)

Following the recommendations of others (e.g. DePuy, et. al., 1980), regressions using both COST and ln(COST) measures as dependant variables were run. Using the natural log reduces the effect of extremes on the regression (particularly important when sample size is small). Additionally, regressions using COST as the dependant variable were found to be heteroscedatic (larger residuals at larger values of cost). This violates an assumption of regression that error variance is constant over all observations, resulting in residuals that are not of minimum variance. A common solution to this problem is to log the dependant variable (see Neter and Wasserman, 1974). Findings from using the two alternative measures were similar, but the use of ln(COST), produced higher R^2 values. Those results (Models 1-3) are in Table 6.

All models in Table 6 are highly significant and explain a large proportion of the variance in production cost. All coefficients for the STAND, ADVANCE and SERIES predictors are also significant and positive, consistent with the hypotheses. The

TABLE 6

COST REGRESSIONS - ALL AIRCRAFT

Model	Dependent Variable	Independent Variables	Coeff.	t	Prob.*	Model Statistics
1	FRAMCOST	Intercept	-792	---	---	F = 21.30
		PSTAND	.206	6.17	.0001	Prob. = .0001
		PADVANCE	.212	5.11	.0001	R^2= .67
		SERIES	.363	2.07	.0233	Adj. R^2 = .64
2	PLATCOST	Intercept	-.706	---	---	F = 27.71
		PSTAND	.219	7.36	.0001	Prob. = .0001
		PADVANCE	.198	5.35	.0001	R^2= .73
		SERIES	.388	2.48	.0094	Adj. R^2 = .70
3	FLYCOST	Intercept	.321	---	---	F = 34.19
		FSTAND	.099	7.95	.0001	Prob. = .0001
		FADVANCE	.092	5.97	.0001	R^2= .75
		SERIES	.446	2.96	.0028	Adj. R^2 = .73
4	FLYCOST	Intercept	.312	---	---	F = 39.94
		FSTAND	.104	9.84	.0001	Prob. = .0001
		PADVANCE	.189	6.48	.0001	R^2= .83
		SADVANCE	.589	2.36	.0122	Adj. R^2 = .81
		SERIES	.329	2.55	.0078	

* One tailed tests

conclusion is that both the SOA of technology in general and the extension of technology in individual aircraft explain production cost. And the findings for the SERIES variable indicate an important "premium" in production cost for new designs.

Note that Model 2 explains a greater proportion of PLATCOST than Model 1 does for FRAMCOST. Since the two models contain the same predictor variables, this result is consistent with PSTAND and PADVANCE being surrogates for frame technology and measuring technology SOA and extension for airframes with "noise".

Model 4 in table 6 is an alternative approach to explaining FLYCOST by using the separate ADVANCE measures for platform and systems, the two items making up the flyaway aircraft.[6] The basic conclusion to be drawn from model 4 is that additional explanatory ability is achieved by substituting PADVANCE and SADVANCE for FADVANCE.[7]

Tables 7 and 8 display analogous regressions for two subsamples: new design, first series and old design, follow-on series, respectively. In general, the findings are consistent with those from the full sample: R^2s are high and coefficients are positive and significant. Model and coefficient significance

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[6]All STAND measures, being predicted values from a regression of TECH on time, are linear transformation of each other. Hence FSTAND is included in Model 4

[7]Each model was also run using REACH in place of STAND and ADVANCE. R^2s decreased, but all regressions were highly significant, indicating that a measure reflecting total technology in systems does well as a substitute for the two separate measures reflecting technology trend plus extension.

TABLE 7

COST REGRESSIONS - NEW DESIGN / FIRST SERIES

Model	Dependent Variable	Independent Variables	Coeff.	t	Prob.*	Model Statistics
1	FRAMCOST	Intercept	-.647	---	---	F = 12.90
		PSTAND	.228	4.72	.0001	Prob. = .0004
		PADVANCE	.228	3.78	.0008	R^2= .60
						Adj. R^2 = .57
2	PLATCOST	Intercept	-.509	---	---	F = 15.33
		PSTAND	.239	5.34	.0001	Prob. = .0002
		PADVANCE	.207	3.70	.0009	R^2= .64
						Adj. R^2 = .60
3	FLYCOST	Intercept	.654	---	---	F = 21.87
		FSTAND	.108	6.17	.0001	Prob. = .0001
		FADVANCE	.101	4.31	.0002	R^2= .71
						Adj. R^2 = .68
4	FLYCOST	Intercept	.426	---	---	F = 27.48
		FSTAND	.121	8.45	.0001	Prob. = .0001
		PADVANCE	.198	5.08	.0001	R^2= .83
		SADVANCE	.874	3.02	.0039	Adj. R^2 = .80

* One tailed tests

TABLE 8

COST REGRESSIONS - OLD DESIGN / NEW SERIES

Model	Dependent Variable	Independent Variables	Coeff.	t	Prob.*	Model Statistics
1	FRAMCOST	Intercept	-.499	---	---	F = 12.64
		PSTAND	.174	3.40	.0027	Prob. = .0011
		PADVANCE	.209	3.31	.0031	R^2= .68
						Adj. R^2 = .62
2	PLATCOST	Intercept	-.398	---	---	F = 19.93
		PSTAND	.186	4.44	.0004	Prob. = .0002
		PADVANCE	.206	3.98	.0009	R^2= .77
						Adj. R^2 = .73
3	FLYCOST	Intercept	.466	---	---	F = 23.14
		FSTAND	.087	4.20	.0005	Prob. = .0001
		FADVANCE	.091	3.93	.0008	R^2= .77
						Adj. R^2 = .73
4	FLYCOST	Intercept	.495	---	---	F = 24.86
		PSTAND	.089	4.83	.0002	Prob. = .0001
		PADVANCE	.222	4.82	.0002	R^2= .85
		SADVANCE	.021	.04	.4849	Adj. R^2 = .82

* One tailed tests

declines some from the full sample, which is to be expected given the smaller sample size in the subsamples.

There is one pattern of interest. For follow-on series (Table 8), coefficients for the ADVANCE predictors are larger than for the STAND predictors. (This is generally not the case in Table 7 for the new design aircraft.) The pattern becomes understandable by considering that new designs involve construction from the "ground up" of a new aircraft. Both achieving the current SOA (STAND) and extending it (ADVANCE) must be "paid for". A new series of an existing design, however, involves only "building from" an existing aircraft. Cost should then be more strongly driven by the extension to the existing aircraft that must be "paid for". In short, higher coefficients for ADVANCE for follow-on series is a plausible result, and suggests that the ADVANCE and STAND measures do meaningfully capture elements of importance in explaining the production costs.

PRODUCTION COST VARIANCES

Predictions for production cost, given the technology embodied in the aircraft, can be created by taking the predicted values from the Table 6 regressions (Models 1, 2, and 4) and converting (un-logging) to arrive at estimated production cost. Actual costs of course differ from the estimated costs. Variances can be constructed by subtracting (actual - estimated), which can be interpreted as cost over(under)runs, given the technology produced. These cost variance measures are, of course, not measures of cost overruns or underruns in the most traditional sense of being measured relative to a budget. Traditional variance measures most frequently compare resource inputs (costs) relative to budgeted inputs. The variance measures here compare actual costs with expected costs based on output, where output is measured by the technological performance of the aircraft. Table 9 lists the actual costs (COST), estimated costs (EST) and cost variances (VAR) for the various cost categories.

Plots of the cost variances, arranged by REACH of the flyaway aircraft (FREACH) are in Figures 4 through 6. Two aircraft are highlighted in the figures, the F/A-18A and the F-14A. Figure 6 shows a large positive variance (cost overrun) for flyaway aircraft cost was incurred on the F/A-18A. Figures 4 and 5 show that the F/A-18A also experienced the largest positive variances on airframe and platform costs, suggesting that these two cost elements contributed greatly to the expensive flyaway cost. Figure 6 shows the largest negative variance was experienced on the F-14A; it was inexpensive relative to the technology embodied in it. The large "savings" was apparently not due to an inexpensive airframe or platform; variances in Figures 4 and 5 are close to zero. This suggests that the avionics and weapons systems added to the platform were cost effective. They enhanced the flyaway performance of the aircraft substantially relative to their additional cost.

The variances may be interpreted as measures of cost overruns or cost savings, relative to the technology embodied in the

TABLE 9

PRODUCTION COST VARIANCES

OBS	PROGRAM	FRAMCOST	FRAMEST	FRAMVAR	PLATCOST	PLATEST	PLATVAR	FLYCOST	FLYEST	FLYVAR
1	A-1E/G/H	1.212	1.7455	-0.5335	1.557	2.0889	-0.5319	1.703	1.9417	-0.2387
2	A-3A/8	5.136	9.4677	-4.3317	6.007	10.7262	-4.7192	7.815	10.6813	-2.8663
3	A-4C	1.669	1.6051	0.0639	1.895	2.0100	-0.1150	2.100	2.2091	-0.1091
4	A-4M	2.225	1.9808	0.2442	2.927	2.7128	0.2142	3.714	3.0508	0.6632
5	A-4A/8	1.603	2.6529	-1.0499	1.859	3.2692	-1.4102	1.917	2.9393	-1.0223
6	A-4E/F	1.875	1.9690	-0.0940	2.436	2.5112	-0.0752	2.675	2.8342	-0.1592
7	A-6A	11.286	8.0200	3.2660	12.421	9.7899	2.6311	13.123	10.7900	2.3330
8	A-6E	7.656	5.4811	2.1749	8.883	7.0180	1.8650	10.846	11.3311	-0.4851
9	A-7D	2.950	4.0890	-1.1390	3.847	5.2537	-1.4067	5.012	7.1770	-2.1650
10	A-7E	3.901	4.9069	-1.0059	4.855	6.2291	-1.3741	5.000	9.4962	-4.4962
11	A-7A/8	3.217	7.0675	-3.8505	4.511	8.9808	-4.4698	5.272	9.0227	-3.7507
12	A-10A	4.196	6.1827	-1.9867	5.748	8.5826	-2.8346	7.272	8.0499	-0.7779
13	F-18/C/M	2.229	2.1777	0.0513	2.297	2.6973	-0.4003	2.388	2.9872	-0.5992
14	F-3A/8/C	3.419	2.9304	0.4886	4.205	3.5590	0.6460	4.710	4.7552	-0.0452
15	F-4E	3.649	3.6452	0.0038	4.479	4.6447	-0.1657	5.919	6.0153	-0.0963
16	F-4J	3.511	3.7550	-0.2440	4.416	4.7752	-0.3592	5.924	5.9135	0.0105
17	F-4A/8	7.202	5.4733	1.7287	8.802	6.7439	2.0581	9.613	6.7090	2.9040
18	F-4C/D	.	.	.	.	.	.	5.753	4.7770	0.9760
19	F-8A/8/C	3.746	3.6788	0.0672	4.334	4.5077	-0.1737	4.475	5.0313	-0.5563
20	F-9F/H	0.655	1.8028	-1.1478	0.856	2.2431	-1.3871	0.939	2.4442	-1.5052
21	F-14A	13.082	12.8392	0.2428	17.333	16.4507	0.8823	23.901	29.5799	-5.6789
22	F-15A	10.252	7.8038	2.4482	15.446	10.4991	4.9469	19.356	11.4349	7.9211
23	F-16A	4.045	6.8782	-2.8332	6.069	9.7101	-3.6411	9.641	10.2310	-0.5900
24	F/A-18A	18.854	6.9235	11.9305	22.197	9.8477	12.3493	23.968	16.7833	7.1847
25	F-84F	6.520	2.2941	4.2259	6.020	2.6750	3.3450	5.943	2.7068	3.2362
26	F-86D	0.752	1.3388	-0.5868	1.118	1.6176	-0.4996	1.458	1.7129	-0.2549
27	F-86F	0.887	1.2778	-0.3908	1.028	1.5487	-0.5207	1.095	1.7415	-0.6465
28	F-89D	2.471	1.1814	1.2896	2.831	1.4393	1.3917	3.496	1.6884	1.8076
29	F-100D	1.698	1.6247	0.0733	2.426	1.9849	0.4411	2.659	2.3624	0.2966
30	F-100A/C	2.939	2.0049	0.9341	3.709	2.4968	1.2122	3.856	2.7333	1.1227
31	F-101A/8	5.771	4.8455	0.9255	6.735	5.7839	0.9511	7.291	8.0596	-0.7686
32	F-102A	6.802	3.4071	3.3949	8.125	4.1297	3.9953	9.206	5.3472	3.8588
33	F-104A/8	2.004	2.5281	-0.5241	3.830	3.2009	0.6291	3.773	3.6381	0.1349
34	F-1058/D	10.047	7.3465	2.7005	10.952	8.7374	2.2146	12.280	10.8976	1.3824
35	F-106A/8	7.014	4.7065	2.3075	7.897	5.7648	2.1322	12.016	7.7213	4.2947
36	F-111A	.	.	.	.	.	.	23.510	20.5358	2.9742
37	F-111D	.	.	.	.	.	.	24.141	20.9804	3.1606
38	F-111F	9.827	13.7861	-3.9591	14.121	16.6080	-2.4870	20.897	26.3578	-5.4608

FIGURE 4

PLOT OF FRAME COST VARIANCE VERSUS FLYAWAY REACH

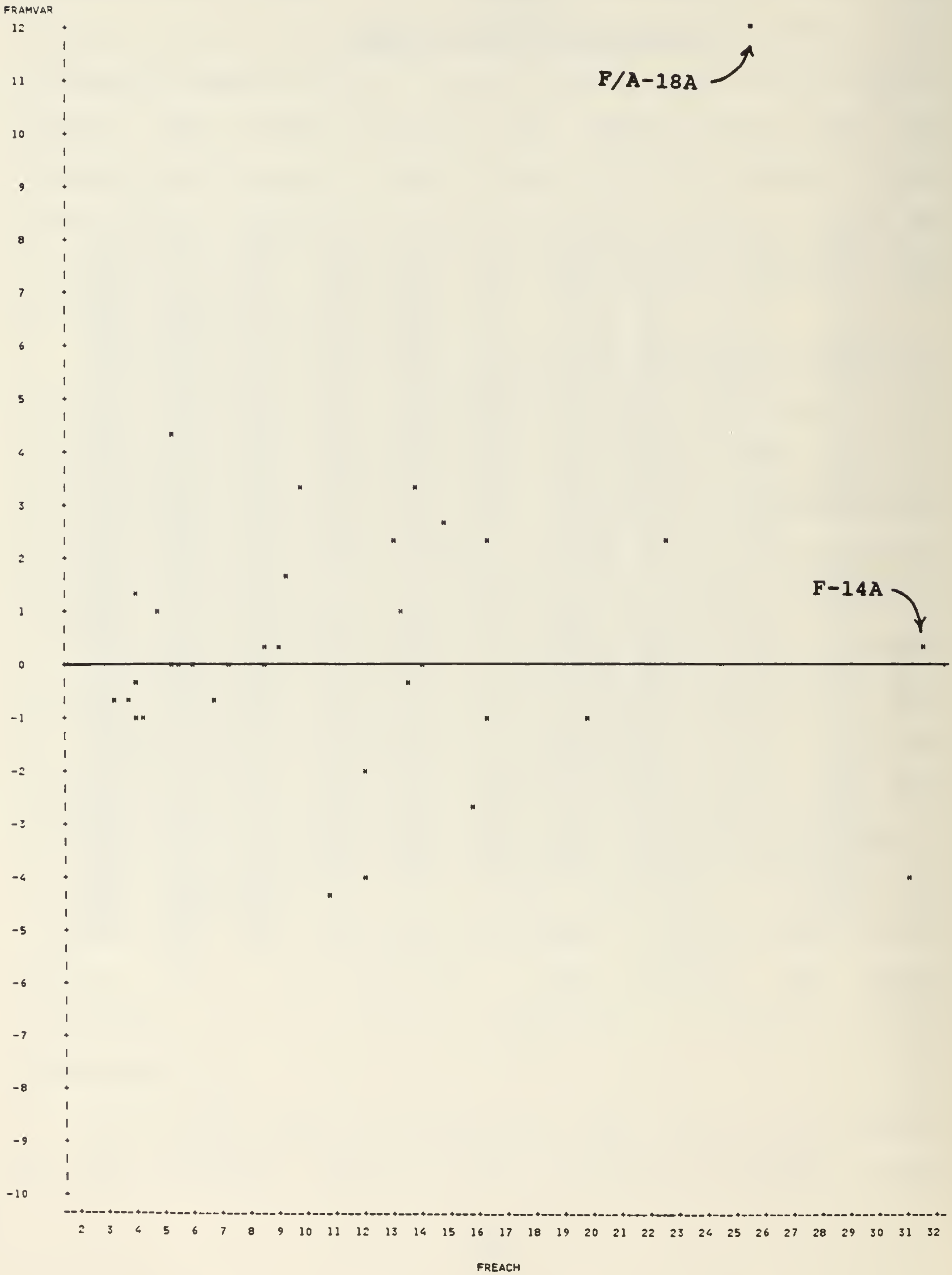


FIGURE 5

PLOT OF PLATFORM COST VARIANCE VERSUS FLYAWAY REACH

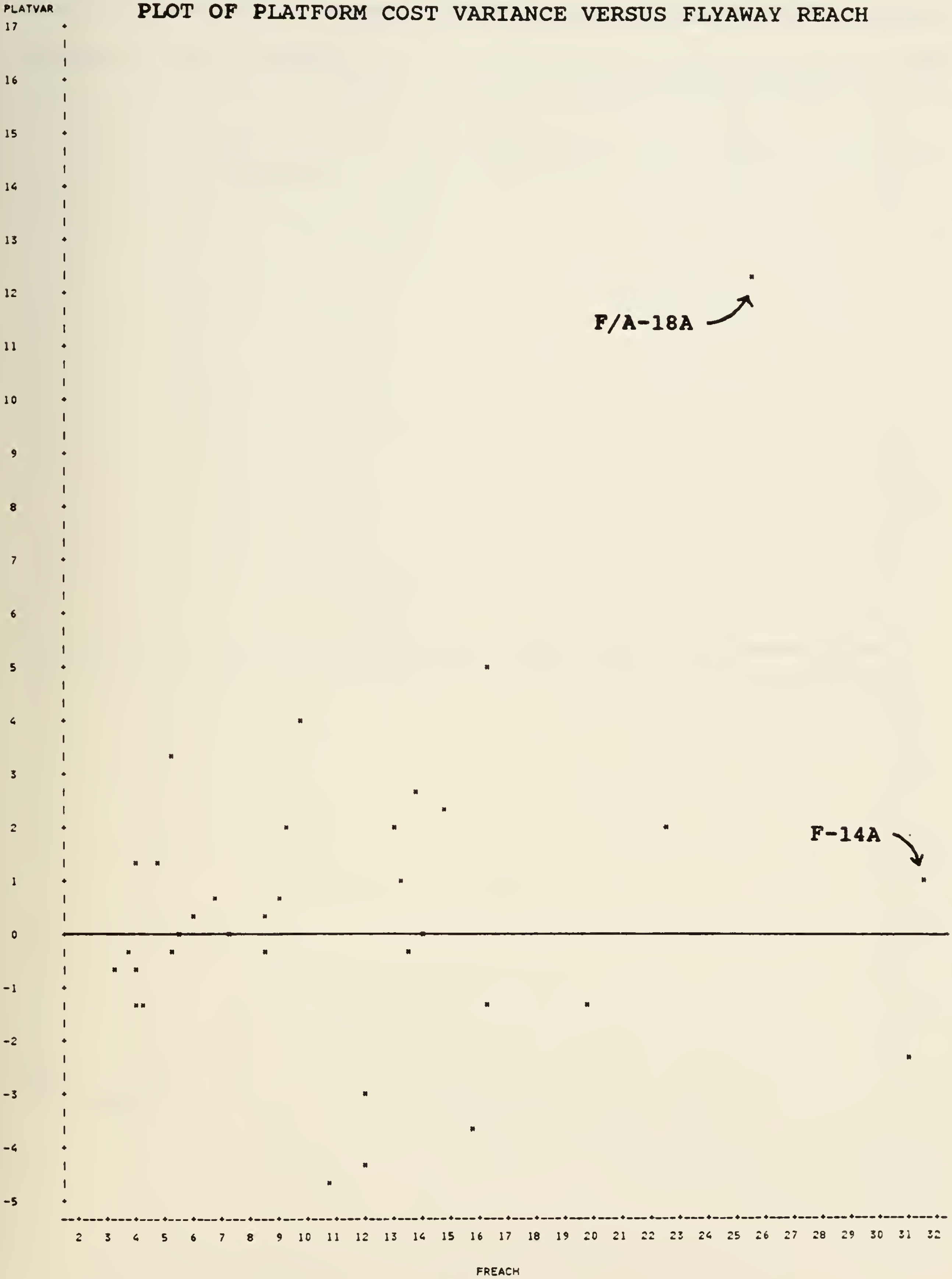
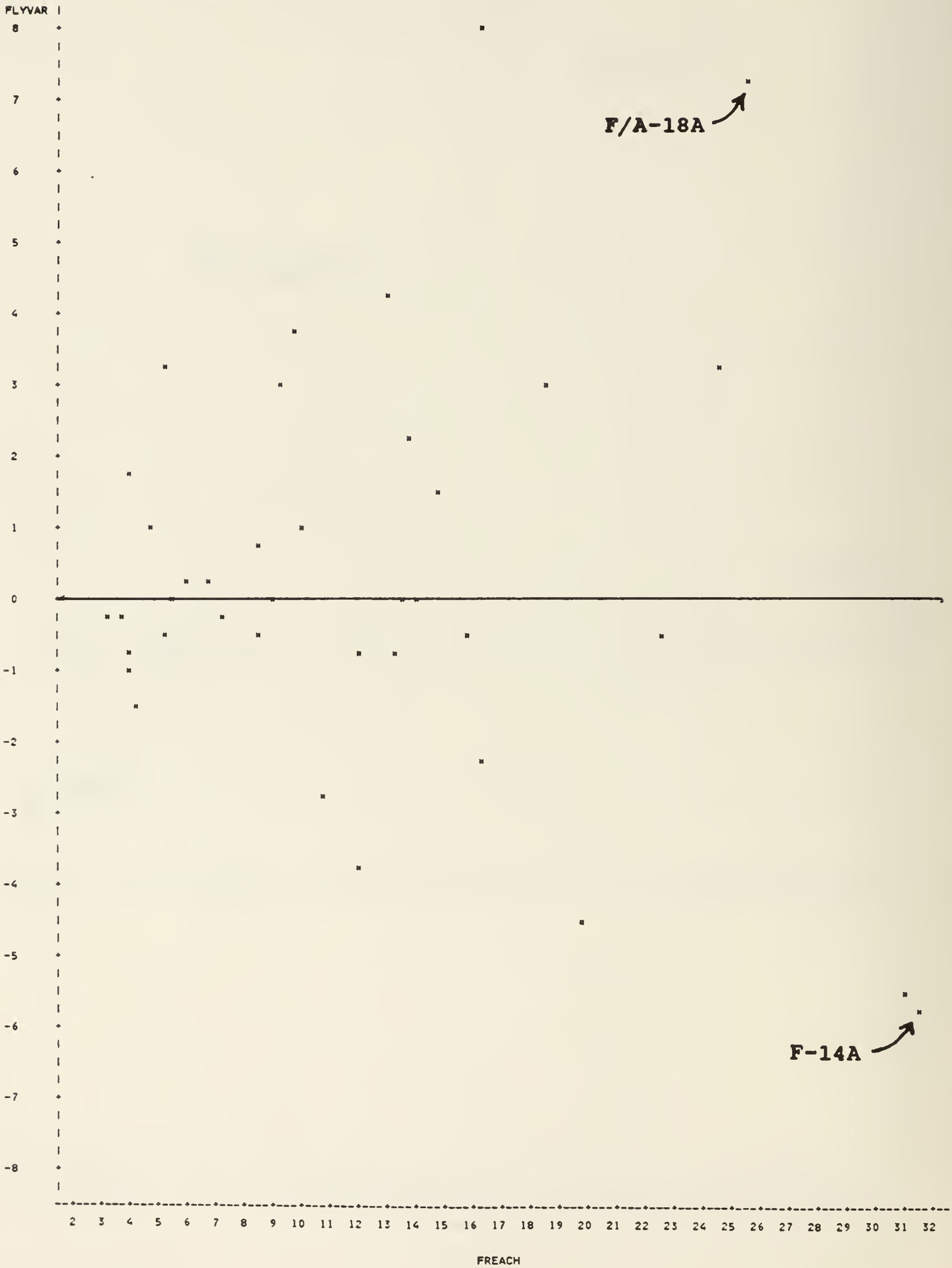


FIGURE 6

PLOT OF FLYAWAY COST VARIANCE VERSUS FLYAWAY REACH



systems. The following chapters address the question of possible causes of the variances.

IV. EXPLAINING VARIANCES - PROGRAM AND ENVIRONMENT FACTORS

Clearly defense procurement, particularly for major weapon systems, is specialized in nature. Both the product and market are not typical of products and markets in general. Major weapon systems are large dollar items which may represent a substantial segment of a manufacturer's business. Major weapons systems incorporate significant innovation with state-of-the-art hardware and substantial uncertainty in development. The market for defense systems is unusual, with a single (monopsonistic) buyer and usually only a few (oligopolistic) sellers. Pricing strategy for such items is likely to be an important strategic decision.

Prices are determined primarily through a bid and negotiation process. A bid is accepted and a contract for a specified number of units is negotiated prior to production. Prices (costs to the government) are specified in the contract and are based on costs incurred ("cost plus") using some agreed upon formula. Cost estimates and their source are disclosed at the time of contract negotiation, so some agreement on the validity of cost estimates is established up front.

When does the government pay "too much" or "too little" for high technology systems? Or phrased alternatively, what conditions are associated with positive or negative cost variances, given the technology embodied in the system? Several factors might influence the price that would be offered by the contractor, and accepted by the government, and consequently have some impact on program costs. The factors fall into three broad areas: 1) program characteristics, 2) the political environment, and 3) the economic environment.

Several variables are discussed below. Each is an attempt to reflect some feature of a program or the procurement environment existing at the time of program initiation. For each factor, how that factor might influence the prices that are offered by contractors and accepted by DoD are discussed. To the extent to which these factors influence prices paid, they provide possible explanations for cost variances experienced. Recall that higher (positive) cost variances reflect cost overruns and lower (negative) variances reflect cost savings. Additionally, note that prices charged by a manufacturer are costs to the government.

EXPLANATORY VARIABLES

Program Value. Larger programs may be associated with greater risk to a contractor. If a program is "small", experiencing unexpected costs or losses on the program, while damaging to a firm, would likely not be critical. In contrast, unfavorable performance on a "large" program could have significant implications for the performance of the firm as a whole. Greater down-side financial risk exists. Additionally, larger programs may, because of their size and complexity, be more difficult to manage and control. Greater managerial risk exists. Consequently, it was expected that, as the size of a program (as measured by the dollar value of the program to the contractor) increased, contractors would seek, and be allowed, a "premium" to compensate for additional risk.[8] Hence, program value is hypothesized to be positively associated with cost variance.

H_4: Cost Variance = +f (Program Value)

Number of Lots. Features of the acquisitions environment preclude the use of a single, unchangeable contract covering all units to be manufactured during a weapon system acquisition program. Due to the complex nature and state-of-the-art technology involved in major weapon systems, contracts may be revised to accommodate design and production changes. Additionally, because of the nature of the federal budget process, funding for units procured under a weapon system program is reviewed and approved on an annual basis. The result is that system procurement typically occurs in stages under different contracts, each covering the acquisition of a distinct "lot", consisting of a subset of the total number of units produced. Contractors frequently "buy-in" to a program with a low bid for the initial lot contract, and attempt to generate a satisfactory return by negotiating more favorable prices on subsequent lots once their position as the manufacturer has been established.[9] It was expected that a

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[8]Regulations governing DoD procurement under cost plus type contracts specifically authorize increased profit to the contractor (resulting in higher cost to DoD) to compensate both for higher contractor risk and greater utilization of contractor facilities. (See DoD Federal Acquisitions Regulations Supplement, Part 215.)

[9]Buying-in with an initial low bid is cited by researchers as a common cause of cost growth on government contracts. The ability of a contractor to increase price after its position as the manufacturer has been established is reduced if a second source manufacturer can be set up. But problems related to technology

contractor's ability to increase price would be associated with the number of opportunities for negotiating additional contracts. Consequently, a positive relationship between the number of lots in a procurement program and cost variance was hypothesized.

H_5: Cost Variance = +f (Number of Lots)

Defense Spending. What was the political and budgetary environment like at the time a program was initiated? Were constraints being imposed on defense spending? Were defense or non-defense programs favored? It was felt that contractors would have less incentive to offer a low price (and perhaps government negotiators would have less pressure on them to demand a low price) if the political environment appeared favorable to defense spending.[10] A positive relationship between cost variance and the degree of defense spending (as a proportion of federal spending) at the time of program initiation was hypothesized.

H_6: Cost Variance = +f (Defense Spending)

Program Funding. There is inevitably some uncertainty concerning the long run commitment of the government to individual weapon systems. Long run plans may be made, but the federal budget

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transfer, the existence of proprietary information and the high cost of second source qualification and start up prohibit second sourcing for the types of systems studied here. The impracticality of second sourcing places the sole source manufacturer in a strong negotiating position on subsequent production lots. (See White and Hendrix, 1984, p. 63 and p. 93.)

[10]Evidence from research on pricing strategy in the aerospace industry (Moses, 1989) supports the conclusion that, as defense spending increases, contractors adopt strategies that tend toward higher initial prices for aircraft system.

is discussed and revised annually. Programs that are supported one year by an administration or congress may be cut in subsequent years as the administration, congress or political conditions change. To the extent that long run commitment to a particular weapon system is doubtful, contractors may perceive greater risk and demand a higher price. If commitment to a program is not in doubt, contractors may have greater confidence that program curtailment will not threaten returns and, consequently, offer a lower price, consistent with the lower risk. Commitment to a program is not readily measured, but funds allocated to a program, as reflected in annual obligational authority, may provide an indication of the government's willingness to commit to a program. "Early" allocation of funds may reflect a strong initial commitment. The initial year obligational authority for a program was divided by the total obligational authority over the life of a program to create a measure reflecting the proportion of the project that was funded "up front".[11] This measure of early funding was expected to be negatively associated with cost variance.

H_7: Cost Variance = -f (Program Funding)

Presidential Party. The conventional wisdom concerning the views of the two major U.S. political parties toward defense spending considers Republicans (Democrats) to be biased toward devoting resources to defense (social) programs. A more favorable

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[11]Research by Moses (1989) demonstrates a significant relationship between the degree of initial year funding for weapon systems programs and the adoption of low initial price pricing strategies by contractors.

climate for defense spending may encourage contractors to seek, and the government to accept, higher prices for defense programs. While congress has been generally controlled by Democrats during the period of this study, the Presidency has changed hands several times. A positive association between a Republican presidency at the start of a program and cost variance was expected.

H_8: Cost Variance = +f (Republican Party)

Capacity Utilization. High capacity utilization,[12] ceteris paribus, should typically be associated with a greater number of active projects for a firm and a greater volume of activity. Because of this, two effects may occur. First, fixed capacity and corporate overhead costs may be spread over the larger number of projects, resulting in a relatively lower cost per project.[13] Second, risks associated with a single project may be offset by risks on other projects. This benefit from the offsetting of risks (i.e., a portfolio effect) may permit a contractor to accept a relatively lower price on a specific project. Given one or both

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[12]Capacity utilization was measured for the aerospace industry as whole, rather than for individual firms. Work by Greer and Liao (1984) shows that industry capacity utilization is a better predictor of firm pricing and bid behavior than is firm specific capacity utilization. This result holds because, in a competitive industry, individual firm actions are influenced by the actions of competitors such that the "average" capacity utilization of the industry appears to drive behavior.

[13]Consistent with this hypothesis, Greer and Liao (1987) demonstrate that unit costs are inversely associated with industry capacity utilization in the aerospace industry, when contracts are sole source, cost plus type.

of these effects, the degree of capacity utilization was hypothesized to be negatively associated with cost variance.

H_9: Cost Variance = -f (Capacity Utilization)

Inflation. Inflation makes future dollars worth less than current dollars. When the inflation rate is high contractors may compensate for its effect by building a cushion into the price they offer in order to cover expected higher costs. If this effect takes place, high prices may occur when inflation rates are high. A positive association between the rate of inflation at program start and cost variance was hypothesized.[14]

H_{10}: Cost Variance = +f (Inflation Rate)

General Economic Conditions: Economic conditions - growth or contraction - may influence program cost. If the economy is robust, demand for products should be relatively greater, opportunities for alternative commercial projects supplied by contractors may be more plentiful, and incentives to compete on price for a particular defense contract may be reduced. When economic contraction occurs, new defense programs may appear more appealing and the increased incentives to compete for such contracts may result in lower prices. A positive relationship between the rate of GNP growth at

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[14]Lehman (1988, Chapter 7) argues that the Program, Planning and Budget System builds past inflation into future price estimates; that contractors, aware of the upward bias caused by the built-in inflation factors, automatically raise prices to the level they know is permitted by the inflation factor; and that this process guarantees price escalation. His discussion centers on the acquisition of the F/A-18A.

the time of program start and cost variance experienced on a program was hypothesized.

H_{11}: Cost Variance = +f (GNP Growth)

Table 10 summarizes the explanatory variables and their measurement.

ANALYSIS OF EXPLANATORY VARIABLES

To test the hypotheses that program and environment factors affect the costs incurred to acquire high-technology weapon systems, three multiple regression models were constructed. The cost variances (FRAMVAR, PLATVAR, FLYVAR), representing the portion of cost that could not be explained by the technology in the aircraft, were regressed on the set of explanatory variables. Results are contained in Table 11.

Several findings are evident from the regressions. First, all three models are significant and explain a fair proportion of the variance in the dependent variable. Second, all of the eight predictors (except Presidential Party) have significant coefficients in one or more of the models, and, when significant, the coefficient signs are as hypothesized.

The strongest results, in terms of level of significance and consistency across the three models, are for Program Value, Defense Spending and Inflation; these factors are associated with all three

TABLE 10

PROGRAM AND ENVIRONMENT EXPLANATORY VARIABLES

Program Variables

1. Program Value:	Average annual dollar value of a program over the program's life. Measured in 1981 dollars (millions).
2. Number of lots:	Total number of individual lots contracted for over a program's life.

Political Variables

3. Defense Spending:	Defense spending as a percent of total federal spending. Measured at time of program start.
4. Program Funding:	Initial year obligational authority divided by total obligational authority over the life of a program.
5. Political Party:	Presidential party in power at time of program start. (Republican = 1, Democrat = 0.)

Economic Variables

6. Capacity Utilization:	Percentage capacity utilization of aerospace industry at year of program start.
7. Inflation:	Percentage change in Producer Price Index-Industrial at year of program start.
8. Economic Growth:	Percentage change in price-adjusted GNP at year of program start.

TABLE 11

COST VARIANCE REGRESSIONS - PROGRAM AND ENVIRONMENT FACTORS

Dependent Variable:	FRAMVAR		PLATVAR		FLYVAR	
Explanatory Variables	Coeff.	t	Coeff.	t	Coeff.	t
Intercept	-15.0	----	-17.4	----	-27.6	----
Program Value	.0080	4.05***	.0082	3.90***	.0051	3.02***
Number of lots	.3274	1.81**	.3212	1.66*	-.134	-.65
Defense Spending	17.23	3.60***	15.56	3.42***	9.05	1.66*
Program Funding	-2.50	-.88	-2.48	-.81	-4.43	-1.34*
Presidential Party	-1.02	-1.17	-.49	-.52	.77	.74
Capacity Utilization	-.072	-1.57*	-.076	-1.53*	.0038	.07
Inflation	63.99	4.12***	67.19	4.04***	35.56	2.04**
Economic Growth	6.12	.49	8.02	.60	19.67	1.34*
Model Statistics						
F =	5.02		4.80		2.86	
Prob. =	.0008		.0010		.0179	
R^2 =	.61		.60		.44	
Adj R_2 =	.49		.47		.29	
n =	35		35		38	

* Significant at probability < .10, one tailed tests
** Significant at probability < .05, one tailed tests
*** Significant at probability < .01, one tailed tests

cost variance measures.[15] The conclusions follow from the hypotheses: Larger programs, perhaps because they are more risky or more difficult to manage, tend to be associated with cost overruns. When defense spending is high, cost overruns tend to result. This is consistent with an environment favorable to defense spending leading to acceptance of a higher price by DoD. Cost overruns also tend to follow periods of rapid inflation. As suggested by Lehman (1988), this may be due to an institutionalized planning and pricing system that builds past inflation rates into future cost estimates.

The Capacity Utilization variable is most significant for FRAMVAR and least significant (not significant) for FLYVAR. This pattern is perhaps understandable. Recall that the three costs of interest are progressively more comprehensive measures:

Airframe Cost
\+ Engine Cost
= Platform Cost
\+ Avionics and Weapons Systems Cost
\+ Miscellaneous Cost
= Flyaway Cost

The prime contractor for an aircraft program will be in the aerospace industry. So the aerospace industry capacity utilization measure may be most directly related to the actions of the prime contractor. The prime contractor typically constructs the airframe, but subcontracts out engine and systems manufacture. A

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[15] Of course the tests are not independent. Since flyaway aircraft cost includes platform cost, and platform cost includes airframe cost, the cost measures (and cost variance measures) are interrelated.

high association between aerospace capacity utilization and the costs directly related to the prime contractor's manufacturing efforts (i.e., airframe costs) may not be surprising. On the other extreme, total flyaway cost includes systems, which are typically subcontracted to firms in the electronics industry. Consequently, flyaway aircraft cost should be (relatively) less affected by conditions in the aerospace industry. Thus, the lower association of FLYVAR with aerospace industry capacity utilization may be understandable.

The number of lots variable is also most significant in the FRAMVAR regression and least (not) in the FLYVAR regression. A somewhat analogous explanation may apply. The government contracts with the prime contractor for specific lots. Hence, number of lots is found to be associated with what the prime contractor manufactures (airframes). Arrangements between the prime contractor and subcontractors to acquire electronic systems may be only indirectly influenced by the number of lots. Hence, flyaway cost, which includes the electronic systems cost, is found to be unrelated to the number of lots.

In short, capacity utilization and number of lots may be expected to more strongly influence prime contractor actions and the strongest (weakest) results are found when explaining costs most (least) directly under prime contractor control.

Broadly, the overall findings are consistent with the identified factors (except Presidential Party) influencing costs as expected. Aspects of the program, political environment and economic environment do reflect conditions indicating when cost overruns or savings may be expected.

V. EXPLAINING VARIANCES - FIRM SPECIFIC FACTORS

The purpose of this chapter is to investigate associations between financial and business characteristics of manufacturers and the cost variances experienced on the aircraft produced. Are there systematic relationships between contractor characteristics and cost overruns or cost underruns? The analysis here starts with the premise that contractor characteristics are associated with costs incurred during the production of systems. The objective is to determine the nature of the associations.

The previous chapter documented that cost over/underrun measures (cost variance measures) are significantly associated with program and environment factors. The intent here is to determine if firm-specific factors additionally help to explain over/underruns. This means attempting to explain variance in the cost over/underrun measures that is "left over" or unexplained by the program and environment factors.

Residuals from a regression of Cost Variance on the program and environment factors represent the cost over/underruns unexplained by those factors. The regressions reported in Table 11 were re-run excluding the Presidential Party variable (it was non-significant in all three models and consequently has no explanatory ability) and residuals from those regressions were used as measures of the additional variance potentially explainable by firm-specific characteristics. These residuals are the dependent variable used in the tests reported in this section.[16]

There are four broad problems to address in attempting to explain cost variance by firm-specific financial and business characteristics:

1. Data Source: What data should be used to construct measures of financial and business characteristics? Data from externally reported, public financial statements was used. The primary advantage is availability. The disadvantage is that public financial reports provide aggregated company level data and in some cases data collected at a division or program level would likely be more valuable. The difficulty (impossibility?) of gaining access to internal, proprietary records, particularly for aircraft manufactured decades ago, was considered too great. Given the exploratory nature of the analysis, use of readily available data was considered appropriate.

2. Choice of Measures: Numerous measures of financial condition can be constructed from financial reports. What set of measures should be examined? An empirically derived set of dimensions reflecting financial condition was used as a bases for identifying relevant measures.

3. Timing of Measures: The nature of a contractor's financial condition during production of a particular aircraft may well have an influence on the contractor's ability to control

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[16]Tests using residuals from the Table 11(eleven) regressions (i.e., including Presidential Party) provide the same findings.

costs. However, documenting links between financial condition and cost after production has occurred only establishes an after-the-fact association, which is unlikely to be of value in ex ante cost prediction. Instead, measure of financial condition were constructed using data from the year immediately prior to the initiation of production. Hence, the measures were available prior to production and reflect conditions in existence before production commenced.

4. Hypotheses: Developing arguments concerning why financial condition may be related to cost (and hence cost variance) is both easy and difficult. It is easy to construct a "scenario" describing how some aspect of financial condition may cause actions by contractors to be constrained or facilitated, and how constraining or facilitating contractor actions may affect the costs of production and cause cost over/underruns. Unfortunately, it is sufficiently easy that multiple scenarios leading to contradictory hypotheses can result. It is difficult to specify ex ante what hypotheses should dominate. There simply is no well formulated theory of relationships between financial condition and cost control. Thus, the objective will not be to provide definitive arguments of how financial condition may be associated with cost. A more limited objective, creating "stories" describing possible linkages, will be undertaken. Then empirical tests will provide evidence in support or against particular stories.

DIMENSIONS OF FINANCIAL CONDITION

There is an almost unlimited number of financial ratios that can be calculated from financial reports. The task was to select some subset of possible ratios to reflect dimensions of financial condition such that the set would be both comprehensive and meaningful, while still being manageable. Most financial accounting and financial statement analysis texts group ratios designed to capture specific aspects of financial condition into broad categories, but the grouping process is typically ad hoc. (Profitability, Activity, Liquidity, Solvency are common categories.)

Empirical research using factor analysis of financial ratios (Chen and Shimerda, 1981; Pinches, Mingo and Caruthers, 1973; Pinches, et. al., 1975), however, has identified seven distinct dimensions of financial conditions that the many possible financial ratios reflect. The seven dimensions are both comprehensive (they capture most of the variance in ratios across firms) and stable (the same ratios are associated with the same dimensions across time and across different studies). These studies provide an empirically based taxonomy of financial ratios.

Table 12 provides a list of the ratios analyzed by Pinches, Mingo and Caruthers, categorized by the financial dimension each ratio reflects. While the 48 ratios listed in Table 12 do not exhaust the possible ratios that can be calculated from financial statements, the list is quite comprehensive and includes most commonly used ratios.

TABLE 12

Financial Ratios and Factor Loadings Defining Seven Financial Ratio Patterns for Industrial Firms: 1951, 1957, 1963, 1969

Ratio Number	Ratio Name	Factor Loading 1951	1957	1963	1969
Factor One—Return on Investment					
2	Total Income/Sales	.43	.65	.30	.71
27	Cash Flow/Total Assets	.79	.82	.78	.85[a]
28	Cash Flow/Net Worth	.87	.88	.84	.91[a]
30	Total Income/Total Assets	.94	.93	.91	.89[a]
31	Net Income/Total Assets	.92	.92	.90	.89[a]
32	Net Income/Net Worth	.96	.96	.98	.96[a]
38	EBIT/Total Assets	.89	.91	.87	.91[a]
39	EBIT/Sales	.51	.67	.67	.77
43	Cash Flow/Total Capital	.85	.87	.84	.88[a]
44	Total Income/Total Capital	.96	.97	.85	.97[a]
Factor Two—Capital Intensiveness					
1	Cash Flow/Sales	−.76	−.80	−.54	−.78[b]
2	Total Income/Sales	−.79	−.56	−.25	−.51
3	Net Income/Sales	−.79	−.57	−.02	−.51
4	Current Liabilities/Net Plant	.08	.49	.81	.64
9	Working Capital/Total Assets	.22	.86	.68	.66
14	Current Assets/Total Assets	.27	.87	.87	.81[b]
18	Quick Assets/Total Assets	.26	.62	.54	.77
22	Current Assets/Sales	−.80	−.12	.01	−.11
34	Net Worth/Sales	−.85	−.85	−.82	−.88[a]
36	Sales/Total Assets	.97	.85	.79	.89[a]
37	Cost of Goods Sold/Inventory	.70	.10	−.01	.10
39	EBIT/Sales	−.73	−.47	−.42	−.42
42	Sales/Net Plant	.62	.92	.95	.95[b]
45	Sales/Total Capital	.87	.79	.76	.85[a]
Factor Three—Inventory Intensiveness					
9	Working Capital/Total Assets	.99	.48	.54	.47
14	Current Assets/Total Assets	.88	.43	.42	.45
22	Current Assets/Sales	.52	.91	.90	.87[b]
23	Inventory/Sales	.64	.96	.90	.97[b]
35	Sales/Working Capital	−.71	−.82	−.89	−.77[a]
37	Cost of Goods Sold/Inventory	−.57	−.95	−.96	−.97[b]
Factor Four—Financial Leverage					
6	Debt/Plant	.74	.66	.60	.73[c]
7	Debt/Total Capital	.99	.99	.93	.99[a]
8	Total Liabilities/Net Worth	.75	.85	.91	.76[a]
10	Total Assets/Net Worth	.74	.84	.88	.76[a]
47	Debt/Total Assets	.99	.96	.91	.97[a]
48	Total Liabilities/Total Assets	.75	.87	.87	.76[a]
Factor Five—Receivables Intensiveness					
11	Receivables/Inventory	−.99	−.99	−.99	−.99[a]
16	Inventory/Current Assets	.40	.65	.71	.76[c]
17	Inventory/Working Capital	.22	.52	.71	.46
20	Receivables/Sales	−.90	−.89	−.80	−.82[a]
24	Quick Assets/Sales	−.40	−.68	−.72	−.73[c]
Factor Six—Short-term Liquidity					
5	Current Liabilities/Net Worth	−.85	−.75	−.72	−.71[b]
15	Current Assets/Current Liab.	.77	.82	.80	.91[a]
17	Inventory/Working Capital	−.72	−.53	−.52	−.76[c]
19	Quick Assets/Current Liab.	.75	.70	.72	.81[a]
46	Current Assets/Total Assets	−.91	−.79	−.73	−.78[a]
Factor Seven—Cash Position					
12	Cash/Total Assets	.89	.87	.80	.91[a]
13	Cash/Current Liabilities	.74	.83	.82	.83[a]
21	Cash/Sales	.79	.88	.51	.90[b]
25	Quick Assets/Fund Expenditures	.73	.44	.27	.25
26	Cash/Fund Expenditures	.99	.99	.85	.91[a]

[a] Loaded at .70 or greater in all four years.
[b] Loaded at .70 or greater in three of the years.
[c] Loaded at .70 or greater in two of the years.

Source: Pinches, Mingo and Caruthers, 1983.

For purposes of the current analyses, one ratio was selected to represent each financial dimension. Each ratio selected had a high and stable factor loading on the specific financial dimension it is designed to reflect during the 1951 to 1969 period studied by Pinches, Mingo and Caruthers.[17] Thus, the selected ratios are both strong and consistent indicators of the seven dimensions of financial condition that exist in available ratios. The dimensions and selected ratios follow:

Dimension	Ratio
Profitability:	Income/Sales
Asset Turnover or Capital Intensiveness:	Sales/Assets
Financial Leverage:	Assets/Net Worth
Short Term Liguidity:	Current Assets/ Current Liabilities
Inventory Intensiveness or Inventory Turnover:	Sales/Working Capital
Receivables Intensiveness or Receivable Turnover:	Receivables/Sales
Cash Position:	Cash/Assets

[17]There is one exception. Profit Margin (Income/Sales) was selected to represent the Profitability dimension even though other ratios (i.e. Income/Assets, Income/Net Worth) had higher factor loadings. The reason for this is that Income/Sales is a more "basic" measure of profitability. Financial analysis (see Davidson, Stickney and Weil, 1988, Chapter 6) typically decomposes return on assets (Income/Assets) and return on equity (Income/Net Worth) into separate measures of profit margin, asset turnover and financial leverage. Since asset turnover and financial leverage are two of the other dimensions, use of a profitability ratio that was unaffected by these two dimensions was desired.

Financial data to compute the ratios for the sample firms were collected from annual reports and Moody's Industrial Manuals. Financial data could not be found for two sample observations (from the early 1950's) and those two observations were deleted from further analyses. The ratios were calculated for the year immediately prior to commencement of production.

HYPOTHESES

This section introduces some possible ways that financial condition may be related to cost. Links between each dimension of financial condition and cost are outlined. In general, the arguments for a link between financial condition and cost rest on two general ideas:

a. The measures of financial condition indicate positive or negative financial or business conditions which have implications for the management of operations, the incurrence of costs and cost control.

b. The measures of financial condition indicate conditions which influence the nature or strength of a contractor's negotiation position, influence the negotiated price and, consequently, the cost to the government.

Profitability

This dimension is measured by Income/Sales. High ratio values imply greater excess of revenues over expenses and greater profitability. Possible links between profitability and cost are as follows:

1. Profitability results from an ability to control costs (inputs) relative to revenues (output) and hence is a general indicator of efficiency. This is true for both competitive and non-competitive situations. In competitive situations, the market sets a price for the output and profitability is achieved by controlling costs to produce the output. In non-competitive situations (i.e., sole source, cost plus type contracts) incentive clauses reduce (increase) profit as costs increase (are controlled). Hence, a negative association between Income/Sales and cost is expected.

2. High profitability serves to harden a contractor's negotiation position and results in a higher bid being offered and accepted. Two factors may cause this. First, executives are frequently compensated on the basis of profitability measures and rewarded for increasing profitability. High profitability in the recent past establishes a high standard, which can only be exceeded by continued high profitability.[18] Second, high profitability reduces a firm's need for a particular program. Hence, a positive association between Income/Sales and cost is expected.

3. High profitability is an indicator that a contractor knows how to "manage" cost incurrence and cost allocation on government projects. More specifically, high profitability is achieved by allocating costs to government cost plus type contracts (where costs are reimbursed) and away from commercial or government fixed

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[18]A similar argument, linking profitability to pricing strategy has been made by McGrath and Moses (1987).

price contracts (where costs are absorbed by the contractor). If high profitability has resulted from such successful "management" of the cost accounting process in the past, then high cost on future cost-plus contracts (e.g. aircraft) is indicated. Hence, a positive association between Income/Sales and cost is expected.

Capital Intensiveness/Asset Turnover

This dimension is measured by Sales/Assets. Higher ratio values mean higher asset turnover but lower capital intensiveness. Possible links between capital intensiveness or asset turnover and cost are as follows:

1. High asset turnover indicates high utilization of facilities. High facilities utilization means that fixed capacity costs can be spread over more projects, reducing the cost incurred on individual project, leading to cost savings. Hence, a negative association between Sales/Assets and cost is expected.

2. High asset turnover (low capital intensiveness) indicates that a firm is operating near full capacity, placing constraints on the firm's capacity to handle large new projects. Costs increase at full capacity due to such factors as overtime, diseconomies of scale and the need for new investment.[19] Hence, a positive association between Sales/Assets and cost is expected.

3. High asset turnover indicates that a firm is operating near full capacity. The successful filling of capacity reduces the

[19]Franklin (1984) provides a short analysis of the relationship between capacity and cost.

firm's need for additional projects, which strengthens the firm's negotiation position. The stronger negotiation position results in a higher bid and price.[20] Hence, a positive association between Sales/Assets and cost is expected.

4. A high measure of asset turnovers is "caused" by low measures of assets. Asset measures are low because the assets are old and not being replaced. (Financial statements measure assets in terms of depreciated acquisition costs.) Low asset measures indicates out-dated, inefficient capital assets.[21] Inefficient assets lead to increased production cost. Hence, a positive association between Sales/Assets and cost is expected.

Financial Leverage

This dimension is measured by Assets/Net Worth. High ratio values imply more debt financing and greater leverage. Possible links between leverage and cost follow:

1. Financial leverage (caused by large debt financing relative to equity financing) is an indicator of solvency or long term risk. High leverage implies greater risk, which implies a high cost of raising capital. The high cost of capital places constraints on the firm's ability to invest in capital assets or productivity enhancing programs. These constraints result in less

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[20] Greer and Liao (1987) discuss links between capacity utilization and pricing.

[21] Many financial analysis texts discuss of the measurement of assets using historical acquisition cost may have implications for the conclusions to be drawn from financial ratios. See, for example, Miller (1972).

efficient production and higher cost. Hence, a positive association between leverage and cost is expected.

2. High leverage results in a high cost of external financing. Consequently, the contractor seeks financing via progress payments from the government. The need for government financing weakens the contractor's negotiating position. During negotiation, price is traded off by the contractor in exchange for more rapid progress payments. Hence, a negative association between leverage and cost is expected.

<u>Short Term Liquidity</u>

This dimension is measured by current assets/current liabilities. Higher ratio values mean higher liquidity. Possible links between liquidity and cost follow:

1. Short term liquidity reflect a firm's ability to meet short term obligations to creditors and suppliers. New projects may require substantial outlays to finance inventories and production start up costs. Poorer liquidity may result in delays in acquiring necessary resources and other related costs (less attractive payment or credit terms). Higher liquidity may be associated with greater ability to manage day to day operations, reducing cost. Hence, a negative association between liquidity and cost is expected.

2. Short term liquidity is an indicator of "slack" resources. Slack provides a buffer and allows greater flexibility in responding to unforeseen contingencies or taking advantage of

unforeseen opportunities. This greater flexibility permits greater control over the production process and reduces cost.[22] Hence, a negative association between liquidity and cost is expected.

3. Poor short term liquidity indicates a need for additional financing to support working capital requirements. Contractors with liquidity problems trade off price in exchange for more favorable progress payments, resulting in lower program cost.[23] Hence, a positive association between liquidity and cost is expected.

<u>Inventory Intensiveness/Inventory Turnover</u>

This dimension is measured by the Sales/Working Capital ratio. Higher values of the ratio mean lower inventory intensiveness or higher inventory turnover. Possible links between Inventory and cost follow:

1. The major inventory item for contractors is "work-in-process", the value of projects currently under construction. High inventory intensiveness means that the firm is currently engaged in many projects. Overhead costs can be spread over the many projects, reducing costs on each project. Hence, a positive association between Sales/Working Capital and cost is expected.

2. High inventory intensiveness indicates that the firm is currently engaged in many projects. Undertaking additional

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[22]Bourgeois (1981) reviews the role that slack plays in controlling production.

[23]Macias (1989) suggests this tradeoff between price and progress payments.

projects may strain the firm's existing capacity. Insufficient capacity leads to overtime and dis-economics of scale, increasing cost. Hence, a negative association between Sales/Working Capital and cost is expected.

3. Inventory turnover is a traditional measure of operational efficiency. High turnover implies successful management of inventories relative to sales generated. High efficiency implies good ability to control costs. Hence, a negative relationship between Sales/Working Capital and cost is expected.

4. High inventory intensiveness implies many projects in process and less incentive to bid low to secure new projects. High inventory thus implies a stronger negotiation position for the contractor and the consequent ability to extract a higher price. Hence, a negative association between Sales/Working Capital and cost is expected.

Receivables Intensiveness/Receivables Turnover

This dimension is measured by Accounts Receivable/Sales. Higher values of the ratio mean higher receivables intensiveness or lower receivables turnover. Possible links between receivables and cost include:

1. High receivables turnover is a traditional indicator of efficient collection practices and the ability to generate cash readily through operations. Good collection practices provide liquid resources and minimizes the need for external financing. The lower need for financing permits the contractor to tradeoff

rapid progress payments for higher price. Hence, a negative association between Receivables/Sales and cost is expected.

2. High receivables intensiveness implies a high amount of resources tied up in non-producing assets. Poor utilization of assets implies higher costs (higher collection costs, lost opportunity cost). Hence, a positive association between Receivables/Sales and cost is expected.

Cash Position

This dimension is measured by Cash/Assets and a higher ratio value implies a stronger cash position. Possible links with cost include:

1. Higher cash permits favorable credit terms from suppliers reducing raw materials cost and encouraging prompt delivery. Higher cash provides flexibility in responding to unforeseen problems or opportunities. These factors lead to more successful management of operations and lower cost incurrence. Hence, a negative association between Cash/Assets and cost is expected.

2. High cash may indicate unwillingness to invest in productive assets. Building up cash at the expense of reinvestment may be consistent with continued use of older, less efficient assets. Less efficient assets imply higher production costs. Hence, a positive association between Cash/Assets and cost is expected.

ANALYSIS OF FINANCIAL CONDITION VARIABLES

To test hypotheses that financial condition affect the costs incurred to acquire high-technology systems, three multiple regression models were constructed. Residuals from regressing FRAMVAR, PLATVAR and FLYVAR on the program and environment variables (from the previous stage in the analysis) were regressed on the set of financial ratios. Results are contained in Table 13.

Several findings are evident from the regressions. First the R^2s of the models are noticeably lower than those from the regressions in the previous chapter. This is not unexpected. If there is any correlation between the financial ratio variables and any of the previously examined program or environment variables, the ability of the financial ratios to explain cost will be reduced because the dependent variable in these Table 13 regressions is cost that is left unexplained by the program and environment variables.[24]

Only three financial ratios have coefficients that are significant at traditional levels. Profitability (Income/Sales) and Liquidity (Current Assets/Current Liabilities) are significant in all three models, while Capital Investment (Sales/Assets) is significant in two. For all variables, the coefficient signs are consistent across the three models.

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[24]The models are not significant overall and the adjusted R^2 values are quite low. However both model significance and adjusted R^2 are affected by the inclusion in the models of the various ratios that were insignificant. Excluding these ratios improves significant and adjusted R^2, while having no effect on the importance of the three significant variables.

TABLE 13

COST VARIANCE REGRESSIONS - FINANCIAL CONDITION

Dependent Variable[1]:	FRAMVAR			PLATVAR			FLYVAR		
Explanatory Variables	Coeff.	t		Coeff.	t		Coeff.	t	
Intercept	-2.79	-		-2.66	-		-1.58	-	
Income/Sales	94.10	2.50	***	105.7	2.66	***	108.6	2.48	***
Sales/Assets	1.98	2.36	**	1.87	2.11	**	.97	1.05	
Assets/Net Worth	.23	.42		.47	.82		.41	.64	
Curr. Assets/Curr. Liab.	-1.47	-1.82	*	-1.51	-1.76	*	-1.59	-1.72	*
Sales/Work. Capital	-.15	-1.05		-.17	-1.07		-.04	-.29	
Acct. Rec./Sales	-8.43	-.85		-14.4	-1.37		-14.6	-1.33	
Cash/Assets	-1.75	-.50		-2.67	-.72		-1.38	-.36	
Model statistic									
F =	1.31			1.25			1.24		
Prob. =	.285			.316			.315		
R^2 =	.27			.26			.24		
Adj. R^2 =	.06			.05			.05		

* significant at probability < .10, two-tailed test.
** significant at probability < .05, two-tailed test.
*** significant at probability < .02, two tailed test.

[1]Dependent variables are the residuals from regressing FRAMVAR, PLATVAR and FLYVAR on the program/environment variables.

The strongest result is for Profitability. The positive coefficient is consistent with some of the arguments offered earlier. Higher (lower) profitability is associated with cost overruns (cost savings). Contractors that are profitable may negotiate from a stronger position, be able to secure a high price, leading to actual costs to the government in excess of "should costs" based on the technology embodied in the aircraft. The findings are also consistent with the argument that contractors that know how to "manage" cost incurrence or cost allocation on government contracts achieve high profitability and this high profitability is associated with cost overruns.

The positive association of cost with Sales/Assets indicates that cost overruns are associated with high asset turnover or, alternatively, with low capital intensiveness relative to the volume of operations. This result is consistent with various interpretations. Low investment in assets relative to operations may signal a situation where a contractor has not been adequately replacing productive capacity. The inadequate investment results in cost overruns due to inefficiencies caused by older, less productive assets or cost overruns due to dis-economies of scale associated with initiating a new project when productive capability is lacking. The result is also consistent with high utilization of existing assets resulting in a stronger bargaining position for a contractor and a resultant higher price.

Capital intensiveness was not significant in explaining Flyaway aircraft cost. A plausible explanation is analogous to that offered to explain some of the findings from the previous tests involving program and environment variables. Flyaway aircraft cost includes, in addition to airframe and engine cost, the cost of avionics and weapon systems, which are subcontracted out. Perhaps it is reasonable that the capital intentiveness of the prime contractor is more likely to affect the cost of components directly manufactured by the prime contractor (i.e., the platform cost).

The weakest (significant) result was for liquidity. Higher liquidity is associated with cost savings. This is consistent with higher liquidity permitting contractors to better manage relationships with suppliers and creditors, and better respond to unforeseen problems or opportunities. The contractor's flexibility results in better control of costs.

VI. SUMMARY, CONCLUSIONS, RECOMMENDATIONS

SUMMARY AND CONCLUSIONS

The objectives of this study were twofold:

a) To determine if the degree of technological sophistication of a system and the degree to which a new system represents a technological advance are indications of the production cost that can be expected for the system. If so, to establish a model depicting the association.

b) To identify factors, knowable prior to production, that may be associated with good or less-successful cost control and test for such associations.

The analysis was conducted using a sample of military aircraft systems. The initial sample consisted of 47 conventional-takeoff-and-landing aircraft, performing fighter and/or attack missions, produced during the 1950-1980 period.

Data reflecting two summary measures of performance for each aircraft were collected from prior research conducted by the Analytic Sciences Corporation. These measures were for airframe performance and aircraft system performance. These measures were created using a judgmental multi-attribute utility function and reflected such factors as payload, range, maneuverability, speed and survivability. These measures were used to define three summary measures of the technology embodied in components of an aircraft: a. platform technology (PLATTECH), b. Avionics and weapon system technology (SYSTECH), and c. flyaway aircraft technology (FLYTECH).

Independently, each of the three "TECH" measures was regressed against the year in which the aircraft were first manufactured. This produced a trend line (equation) of technology over time. Two measures were derived from this process:

a) STAND - a measure of the average state-of-the-art of technology at the time of production of an aircraft (i.e. the predicted value from the trend line), and

b) ADVANCE - a measure of the extension in technology for each aircraft beyond the existing state-of-the-art (i.e. residuals from the trend line).

These two measures (for each component - platform, systems, flyaway aircraft) were used in later analysis.

Measures of production cost for aircraft were then described. The cost used to represent aircraft cost was the cumulative average cost (CAC) of producing 100 units. Calculation of the CAC involved fitting learning curves to the series of costs for successive lots produced for each aircraft. The approach was considered to result in comparable cost figures for aircraft, given that production for different aircraft occurred in different lot sizes and experiences different learning rates. CACs were provided for three different components of each aircraft: a. airframe cost (FRAMCOST) b. airframe plus engine cost (PLATCOST), and c. flyaway aircraft cost (FLYCOST). The CACs were used in the subsequent analysis.

The first objective was to determine if measures of the state-of-the-art and extension in technology (STAND and ADVANCE) were predictive of cost (FRAMCOST, PLATCOST, FLYCOST). Regression models established that both STAND and ADVANCE were highly significant in explaining cost. R^2 values for the regression models ranged from 67% for FRAMCOST to 83% for FLYCOST. The obvious conclusion is that technology related measures are important predictors of production cost. Additionally, there was some evidence that ADVANCE was a more important predictor than STAND in explaining the production cost of a new series of aircraft of an already existing design. This is consistent with the idea that, for a new series of an existing aircraft design, it is the extension in technology beyond the existing design that must most strongly affects cost.

Measures of cost variances (cost overruns or cost underruns) were then created by comparing actual production cost with cost predicted by the models.

The second objective of the study was to identify factors that might explain the apparent cost over/underruns. The factors identified fell into three categories: 1) characteristics of the aircraft acquisition program, 2) characteristics of the economic or political environment when production commenced, and c) financial characteristics of the prime contractor. Generally, the various factors were measured prior to production. Hence, they are knowable ex ante and may provide the basis for predicting when cost overruns or cost savings may be expected. Regression analysis was used to test for associations between cost variances and the various factors identified.

Eight program and environment factors were analyzed first. Collectively the program and environment factors were able to explain from 44% to 61% of the cost over/underruns. Observing signs of the regression coefficients for the individual program and environment variables, the strongest findings were:

1) Cost overruns occur on programs that have a large dollar value. This suggests that large programs are more difficult to manage or control, leading to increased cost; or large programs are considered more risky and contractors are compensated for this additional risk by a higher price (cost to DoD) being allowed.

2) Cost overruns occur when defense spending is high. This suggests that a political environment that is favorable to defense spending leads to higher bids offered by contractors and accepted by DoD.

3) Cost overruns occur when inflation, prior to the commencement of production, is high. This is consistent with contractors building an inflation cushion into their bids.

There was weaker evidence that cost savings are associated with higher capacity utilization in the aerospace industry (fixed capacity cost may be spread over a larger number of projects, reducing cost) and that cost overruns are associated with the number of production lots (additional lots lead to additional contracts and offer a contractor the opportunity to raise prices).

It is interesting to note that seven of the eight program or environment variables were significant explanatory factors of cost in one or more of the tests and that the hypothesized relationships of the variables with cost over/underruns were supported. This provides indirect confirmation that the technology-based models were providing meaningful predictions of cost.

Seven financial ratios, reflecting distinct dimensions of contractor financial condition, were analyzed next. Again, regression analysis was used. While it was easy to identify dimensions of financial condition, it was difficult to specify ex ante the manner in which financial condition would be associated with cost over/underruns. Numerous hypotheses were offered. Collectively the financial ratios were only able to explain between 24% to 27% of the (remaining) variance in cost over/underruns. Three relationships of interest resulted:

1) Cost overruns tend to occur on programs manufactured by contractors which have been highly profitable prior to program start. One possible explanation is that such contractors are in a stronger bargaining position and are able to negotiate a higher price.

2) Cost overruns tend to occur on programs manufactured by contractors with low capital intensiveness. This suggests that adequate facilities are a must in reducing program cost.

3) Cost overruns tend to occur on programs manufactured by contractors with poor liquidity. This is consistent with liquidity

problems hindering the management of day to day operations, leading to cost increase.

RECOMMENDATIONS

Given that the technology measures were found to be strongly associated with production costs, additional attention to these relationships seems warranted. One direction would be to attempt similar applications in settings other than aircraft. A major problem in addressing other applications is in the availability of suitable data for measuring technology state-of-the-art and extensions in technology. Hence, a general recommendation is that efforts be made to develop and maintain such data bases.

Another area of potential importance is the measurement of technology. Given that even the simple technology measures used in this study were quite useful, attention to the issue of technology measurement methodology may be valuable and lead to improved models. There are various alternative approaches to the measurement of the SOA of technology offered in the published literature. A study investigating the alternative approaches could provide useful insights: Do alternative approaches lead to similar measures of technology SOA and extension? Are particular approaches more appropriate in particular situations?

With respect to the factors that were found to be related to cost over/underruns, there is much room for further work. The findings here indicate that plausible relationships tend to exist between program, environment or financial characteristics and cost incurrence. But the measures used to reflect these characteristics were, at best, a first cut and need refinement. And true cause and effect linkages between the characteristics and cost need to be more fully specified. Efforts could be directed toward identifying additional factors that might influence cost. And more refined measures of the factors would be helpful. Access to internal contractor data may be useful in this regard. Only after additional work in this area is done would attempts to include these factors in formal estimating models seem warranted.

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